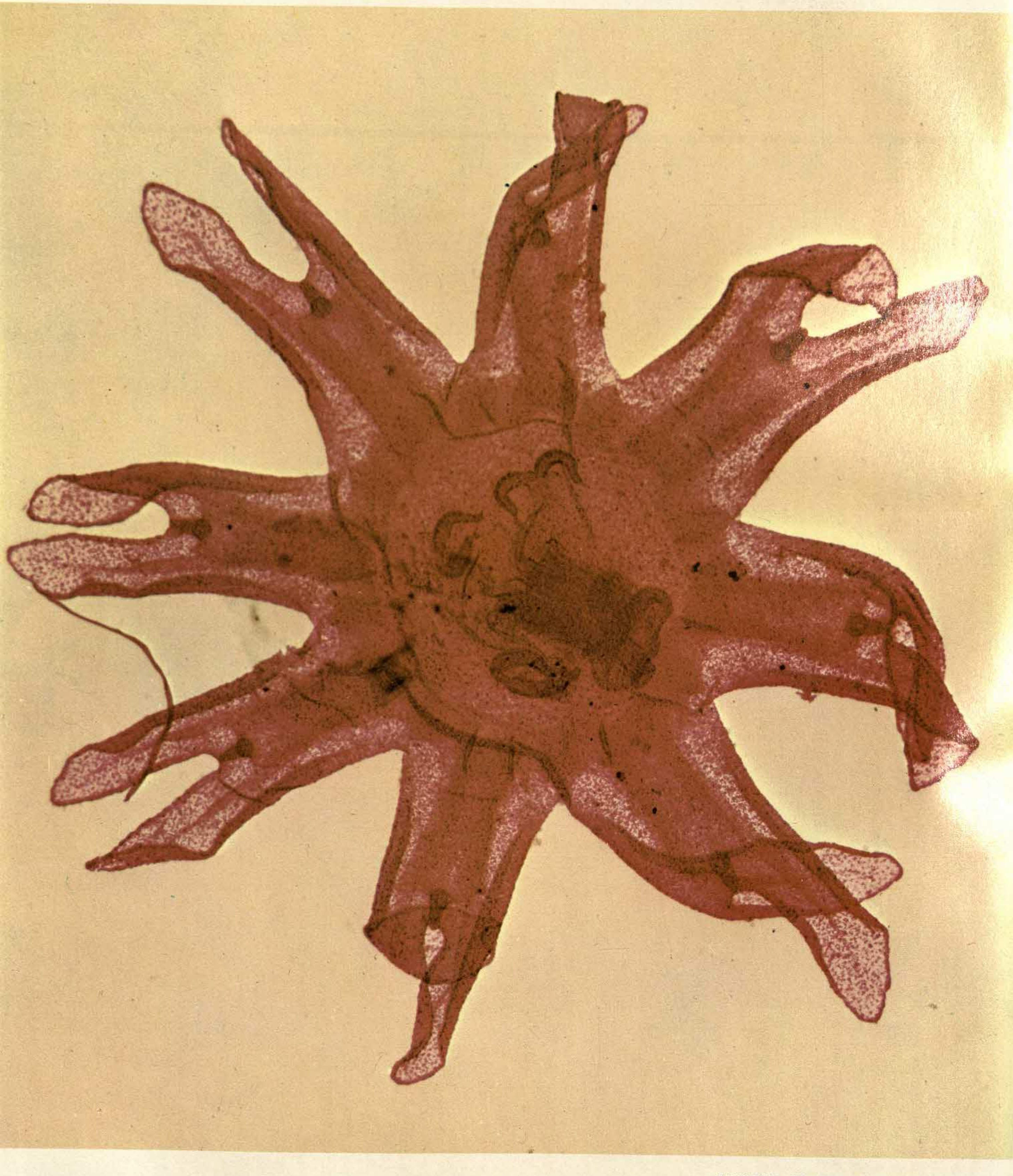
3

Illustrated World of Science Encyclopedia

Biology II:
THE CELL,
REPRODUCTION
AND
DEVELOPMENT

THE WORLD OF SCIENCE



A LARVAL JELLYFISH—*Aurelia aurita*

THE WORLD OF SCIENCE

VOLUME
3

BIOLOGY II

The Cell, Reproduction and Development—Biochemistry—Physiology

with

The Illustrated Science Dictionary

CREATIVE WORLD PUBLICATIONS, INC.
CHICAGO

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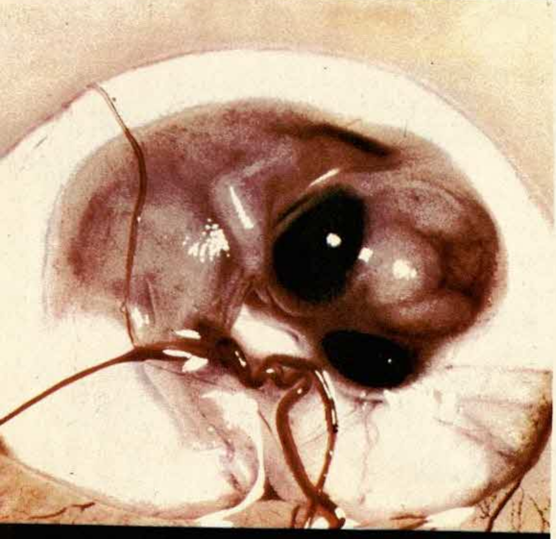

VOLUME 3

BIOLOGY II

The Cell, Reproduction and Development— Biochemistry— Physiology

INTRODUCTION

During the middle third of the present century, life scientists realized that the artificial division of biology into courses of study—by means of such taxonomic groupings as lower and higher plants, microorganisms, invertebrates, and vertebrates—served no useful purpose. These obsolete curricula have been replaced at most colleges and universities by the organizational level of study: that is, by courses in molecular, cellular, genetic, developmental, organismal, population, and ecosystem biology. The latter three areas are emphasized in Volume 2, whereas Volume 3 is concerned with the first five.

In the context of *molecular biology*, the present volume contains discussions of the structure and functions of the proteins, the nature and activities of enzymes, and the factors that influence the catalytic potency of enzymes. Also included are articles on bacterial, plant, and animal cycling of carbon and nitrogen to achieve a continuous transformation of matter from organic to inorganic to organic forms. In addition, the processes whereby food polymers (carbohydrates, fats, and proteins) are converted to energy and new protoplasm are described. Finally, the composition and methods of preservation of milk, an example of a fairly complete food, are included.

In the area of *cellular biology*, Volume 3 contains articles on cytologic technique (microscopy and ultrathin sectioning), cell chemistry, and the structure and function of cell organelles. A cell is not merely a sack of the several compounds that it absorbs from its environment. Rather, these compounds are converted to materials that serve many functions: energy storage, structural components, catalytic chemical transformations, and information storage and transfer. The structure and functions of DNA and RNA, as well as the genetic code, are included with material on membranes, mitochondria, the endoplasmic reticulum, the Golgi apparatus, lysosomes, and centrioles. For the cell to survive, each part must function in harmony with the other parts.

In the field of *genetic biology*, Volume 3 compares and clarifies mitosis and meiosis. Also included are articles dealing with the chemical structure of genetic material; the nature of mutations, chromosomes, linkage and crossing over of genes; and Mendel's laws of inheritance. Sex-linked traits, multiple gene inheritance, epistasis, and penetrance are well discussed. This section concludes with an article on the problems and procedures in studying human genetics.

In *developmental biology*, Volume 3 contains articles on microbial differentiation (the formation of spores, buds, cysts, and medusae), asexual and sexual reproduction in plants, general animal embryology, and avian embryology. Of all the biological areas, the developmental field is one of the most interesting but perhaps the least well understood. When one considers the complexity of an adult organism and recalls that all the organ systems—nervous, circulatory, digestive, and so forth—have all differentiated and grown from a single cell, the more fascinating the embryonic processes become.

Articles dealing with the area of *organismal biology* are contained in both Volumes 2 and 3. In the latter are articles on the tissues and organs responsible for coordination (nervous and hormonal), digestion, respiration, circulation, excretion, and defense against pathogenic microorganisms. Each of these organ systems has had to overcome difficult physicochemical obstacles and to interact harmoniously with each of the other systems. For example, the three ways in which various kinds of animals have solved the problem of ammonia disposal are discussed. Consider also the immense physical problems that have been overcome by the human circulatory system and the extraordinary efficiency of human antimicrobial defense tissues in maintaining large portions of the body in a germ-free state. This section concludes with an introduction to *bionics*, the science that aims to construct mechanical systems based on living systems. Several remarkable examples in bionics are described, and there is little doubt that, together with cybernetics, bionics will become increasingly important in the years ahead.

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PLANT TISSUES | the microscopic structure of plants

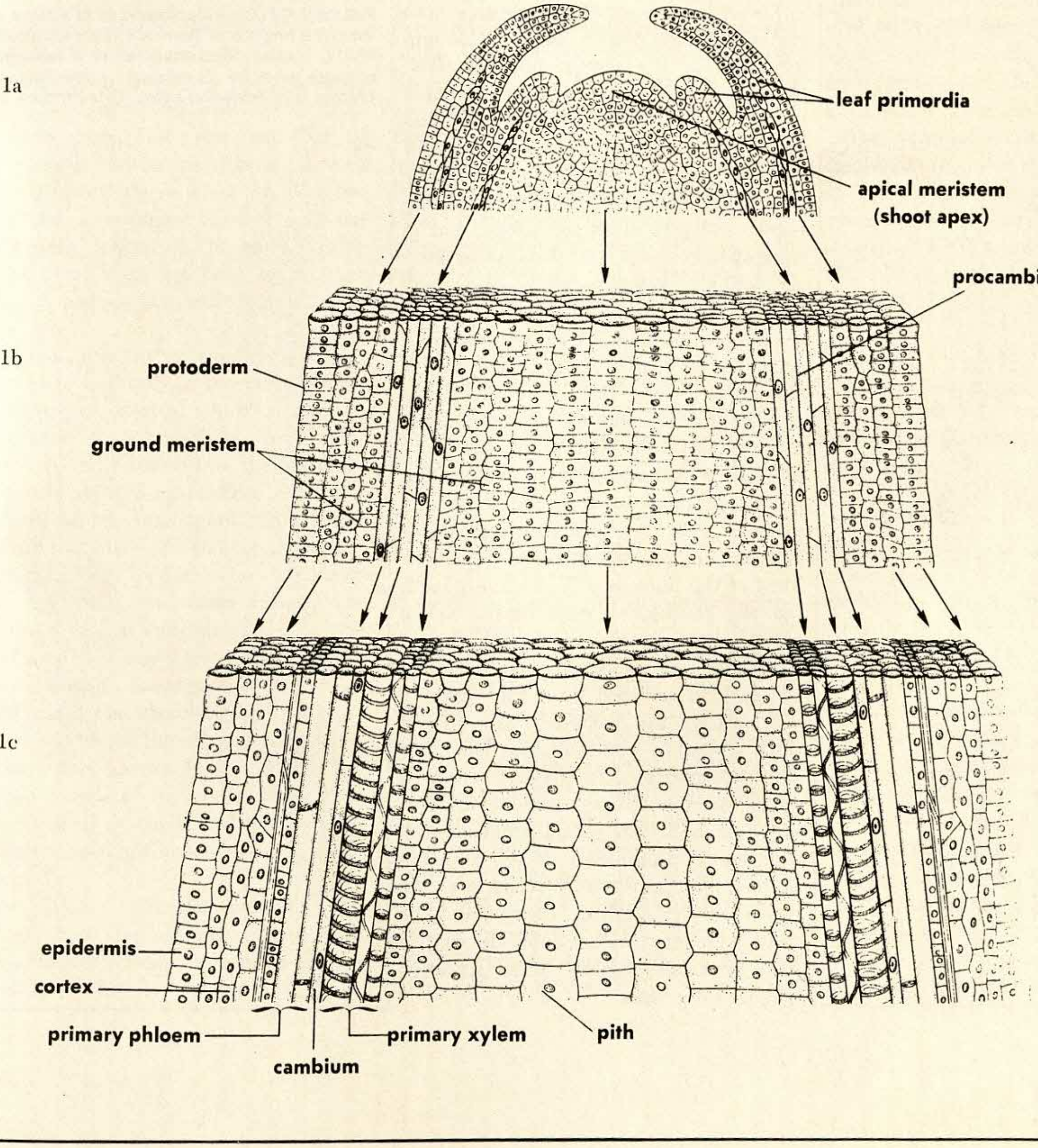
One of the most important and most interesting features of seed plants is their capacity for continuous growth throughout their lifetimes. In this way they differ from most animals, which grow to a characteristic size and then remain at that size for the rest of their lives.

Growth of plants is accomplished by special tissues called meristems. These are composed of thin-walled, embryonic cells that retain indefinitely their ability to divide and produce new cells. Some of the new cells continue to function as meristematic cells; others differentiate into mature tissues with various functions. Among the differentiated tissues are: the vascular tissues that conduct food, water, and minerals through the plant and contribute to its support; the photosynthetic tissues that manufacture food; the fibers that give additional support to the plant; parenchymatous tissues that store food; and the epidermis and cork that surround and protect the plant organs.

APICAL MERISTEMS

Stems and roots grow in both length and width. The meristems responsible for increase in length are called apical meristems because they are located at the apices of the stems and roots. They also are called primary meristems because they are present in the embryo. The zygote, or fertilized egg, from which the embryo develops, represents the first meristematic cell in the life of the new plant. After the first few cell divisions, the embryo consists of a nearly spherical mass of cells; at opposite poles, however, there are two masses of meristematic cells, one representing the young stem tip and the other the young root tip. As these continue to function, an elongated embryo develops and the cylindrical axis of root and stem become evident. It is from the apical meristem of the stem that

PRIMARY TISSUES OF THE STEM — These longitudinal sections through several parts of a stem (Illustrations 1a, 1b, and 1c) show how the apical meristem is responsible for primary growth or growth in length of the stem. The apical meristem produces protoderm, procambium, and ground meristem. From these mature all the primary tissues of the stem. The xylem cells shown here have annular (ring-shaped) and spiral (actually helical) thickenings.

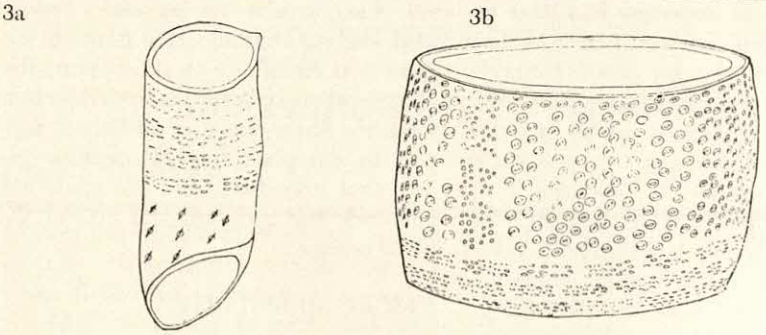


all the cells of the stem and its leaves ultimately derive, whereas all the cells of the root ultimately derive from the apical meristem of the root.

PRIMARY TISSUES OF THE STEM

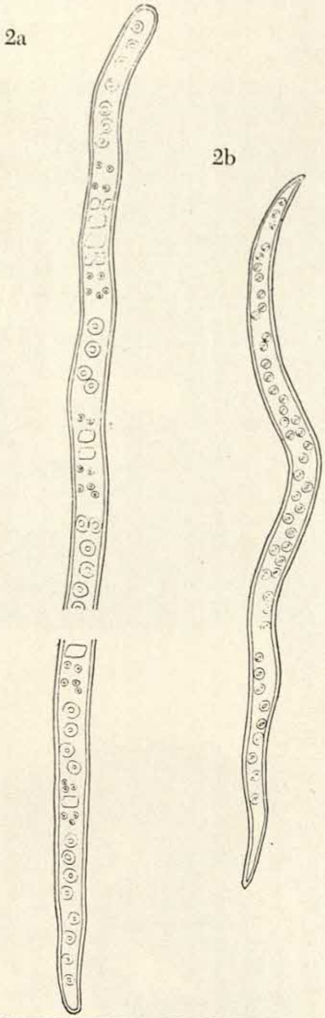
The tissues derived from the apical meristem of the stem are the protoderm, which matures into epidermis; the procambium, which develops into vascular tissues; and the ground meristem, from which derive the cortex and pith.

Epidermal cells form a covering over young plant parts. Their outer surfaces are covered by cutin, a waxy substance impermeable to water. Few or no intercellular spaces exist between epidermal cells. These adaptations help to protect the plant from water loss and from invasion by parasites.



VESSEL ELEMENTS—Mature vessel elements have no end walls. The lateral walls of these vessel elements are pitted. Illustration 3a is a vessel element from box elder (*Acer negundo*); Illustration 3b is a vessel element from white oak (*Quercus alba*).

TRACHEIDS—Tracheids are xylem cells found in all vascular plants. They are cylindrical and have tapering ends. Those shown here are called pitted tracheids because their cell walls are interrupted by circular pits. Illustration 2a is a tracheid from white pine (*Pinus strobus*); Illustration 2b is a tracheid from white oak (*Quercus alba*).



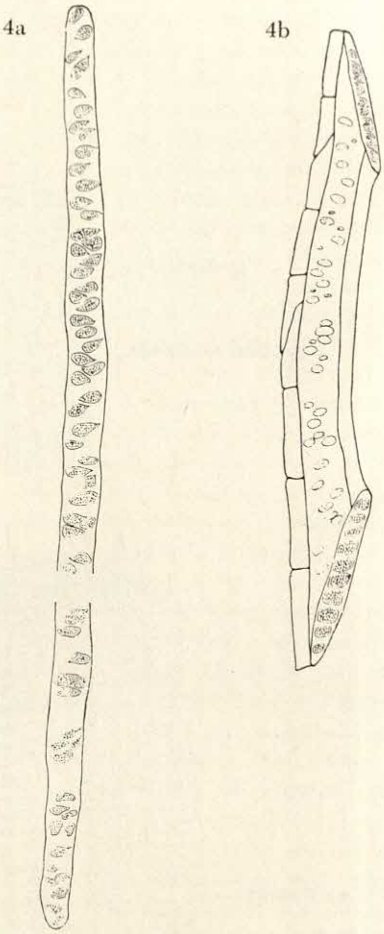
The ground meristem matures into cortex near the outside of the stem and into pith in the center. Both of these tissues are parenchymatous—they consist of thin-walled, living cells that are isodiametric or nearly so, although in older parts of the stem the cells may become somewhat elongated. The cells of the cortex and pith often store food, but in some species the center of the stem characteristically disintegrates, leaving a hollow pith.

The procambium exists as strands of cells that are easily recognized by their elongated shapes, their long axes lying parallel to the long axis of the stem. Procambium cells mature into primary phloem, which conducts food both upward and downward in the stem, and primary xylem, which conducts water and minerals upward from the roots. Most of the phloem cells are living cells, but the conducting cells of the xylem are dead when they are functioning.

Like all cells of seed plants, the xylem cells are surrounded by a thin primary cell wall. To the inside of this wall is a thick secondary cell wall that has characteristic patterns. In primary xylem it often exists as rings (annular thickenings) or as helices (spiral thickenings). The living protoplasm of the procambium cells forms these secondary cell walls; the protoplasm then dies. The dead, elongated xylem cells are shaped like miniature hollow tubes through which water rises.

Two major types of xylem cells conduct water upward—tracheids and vessel elements. Tracheids are present in all vascular plants (the ferns and their rela-

PHLOEM CELLS—Illustration 4a is a sieve cell from the phloem of hemlock (*Tsuga canadensis*), a conifer. Illustration 4b is a sieve tube element and its companion cells from the phloem of a flowering plant (*Liriodendron* sp.).



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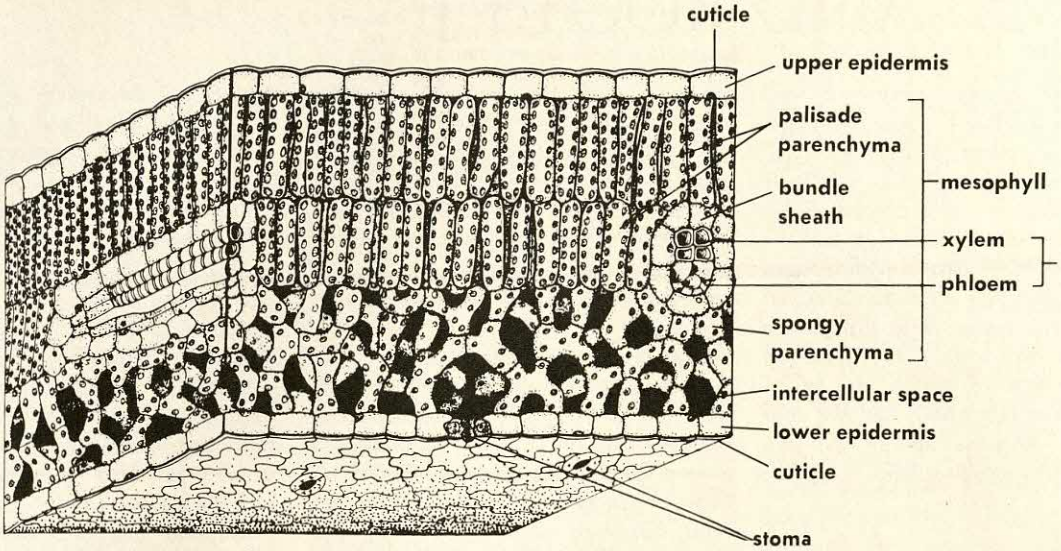


STRUCTURE OF THE LEAF—The leaf consists largely of parenchyma tissue surrounded by epidermis. The epidermal cells secrete a cuticle that greatly reduces water loss from the leaf. Photosynthesis occurs mostly in the palisade parenchyma, which is rich in chloroplasts, and to a lesser extent in the spongy parenchyma which has intercellular spaces in which gases diffuse throughout the leaf.

Carbon dioxide, which is necessary for photosynthesis, enters the leaf through the stomata in the epidermis. Oxygen, a by-product of photosynthesis, leaves through the same pathway.

Vascular bundles, through which materials are exchanged between the leaf and the stem, consist of strands of xylem and phloem surrounded by a bundle sheath.

tives and all of the seed plants). Tracheids are very long cylindrical cells that seem almost to taper to a point because they have slanted end walls rather than horizontal ones. The upper end wall of one tracheid matches the lower end wall of the tracheid above it; in this way the walls form continuous lines of cells extending the length of the stem. Water passing from one tracheid to another must, of course, pass through the end walls.

With a few exceptions, vessel elements are found only in flowering plants, and they are found in nearly all flowering plants. Like tracheids, vessel elements are cylindrical, but they usually are much shorter and wider than the tracheids of the same plant. A few are so short that they are shorter than they are wide. Very young vessel elements have end walls, and these usually are horizontal, but in more primitive flowering plants they taper somewhat. As the vessel element matures, the end walls disintegrate. The vessel elements are arranged one above the other in a continuous line; this creates hollow tubes that run the length of the stem. The entire tube is called a vessel, and water rising through it does not have to pass through cross walls.

The phloem cells that conduct food in ferns and conifers are called sieve cells, and they resemble tracheids in general shape. They are living cells, however, and they have no secondary cell walls. In flowering plants, food is conducted by sieve tube elements, which are cells that have cytoplasm but no nuclei. Closely associated with sieve tube elements are small companion cells that have no conducting function; like most other living cells, however, they have both cytoplasm and nuclei. It is thought that the nuclei of the companion cells may function for the sieve tube elements as well. Sieve tube elements are arranged end to end, forming sieve tubes.

Fibers are dead, thick-walled cells that are longer and narrower than tracheids and that function as supporting cells. They may be present in the cortex, phloem, or xylem.

SECONDARY TISSUES

Epidermis, cortex, primary phloem, primary xylem, and pith are the only tissues present in the stems of most annual plants (those that live only one season). Biennial plants (those that live two years) and perennial plants (those that live more than two years) grow in width by the action of a cambium. The vascular cambium arises between the primary phloem and the primary xylem, and it produces great quantities of secondary xylem and smaller amounts of secondary phloem. Secondary xylem is the wood, which accounts for nearly all of the volume of an old stem.

In most perennial plants a cork cambium arises beneath the epidermis; the cork cambium produces cork, the outermost tissue of the bark.

The vascular cambium and the cork cambium are called secondary meristems (because they develop later than the primary meristems) and lateral meristems (because of their position in the plant). The tissues they produce are called secondary tissues.

LEAVES

Leaves arise as small swellings called leaf primordia that develop from the sides of the stem immediately below the apex. The center of the leaf consists of mesophyll, which is mostly parenchymatous tissue. The cells are rich in chloroplasts, in which the plant manufactures food by photosynthesis. Ramifying through the leaf are vascular bundles with xylem, which brings water and minerals from the stem, and phloem, which removes food from the leaf. The entire leaf is surrounded by epidermis, which is punctuated occasionally by openings called stomata. Through the stomata, the carbon dioxide that is necessary for photosynthesis enters the leaf, and the oxygen that is produced by photosynthesis leaves the leaf.

With few exceptions, a leaf will live for only one growing season, and it will consist of only primary tissues.

STEMS AND ROOTS | the ordered complexity of seed plants

About 250,000 known species of seed plants live on the Earth. From dandelion to redwood and from orchid to cattail, they vary greatly in their size and their form. The tissues of which they are made are remarkably similar, however, and the distribution of these tissues within stems and roots follows only a few fundamental patterns. Three major plant groups are considered in this article: the monocots and dicots, both of which are angiosperms (flowering plants), and the conifers, which comprise one of the two major groups of gymnosperms.

MONOCOTS

Cross sections of monocot stems are easily recognized by the arrangement of vascular bundles. The bundles are scattered throughout the stem, although they tend to be more concentrated near the outside of the stem than at the center, and some monocot stems have large, hollow centers. Each vascular bundle contains both xylem and phloem surrounded by a bundle sheath. The xylem and phloem of a bundle lie on the same radius, the xylem closest to the center of the stem. The vascular bundles lie in parenchyma tissue, and the outermost tissue of the stem is the epidermis.

By contrast, monocot roots have no scattered arrangement of vascular tissue. The centers of the roots are occupied by pith that is surrounded by about a dozen or more strands of xylem. To the outside of the xylem lie strands of phloem. Unlike the xylem and phloem of the stem, the tissues in the root lie on alternate radii. Surrounding the phloem is a single layer of pericycle, and beyond this is a single layer of endodermis. The pericycle produces branch roots, and the endodermis regulates the kinds and amounts of dissolved materials that enter the xylem in the water absorbed by the root. Beyond the endodermis is a relatively wide layer of cortical cells. Both the cortex and the pith store food. The outermost layer of the root is a single layer of epidermal cells.

Most monocots are annual plants with only primary tissues. They have no cambium and no secondary growth.

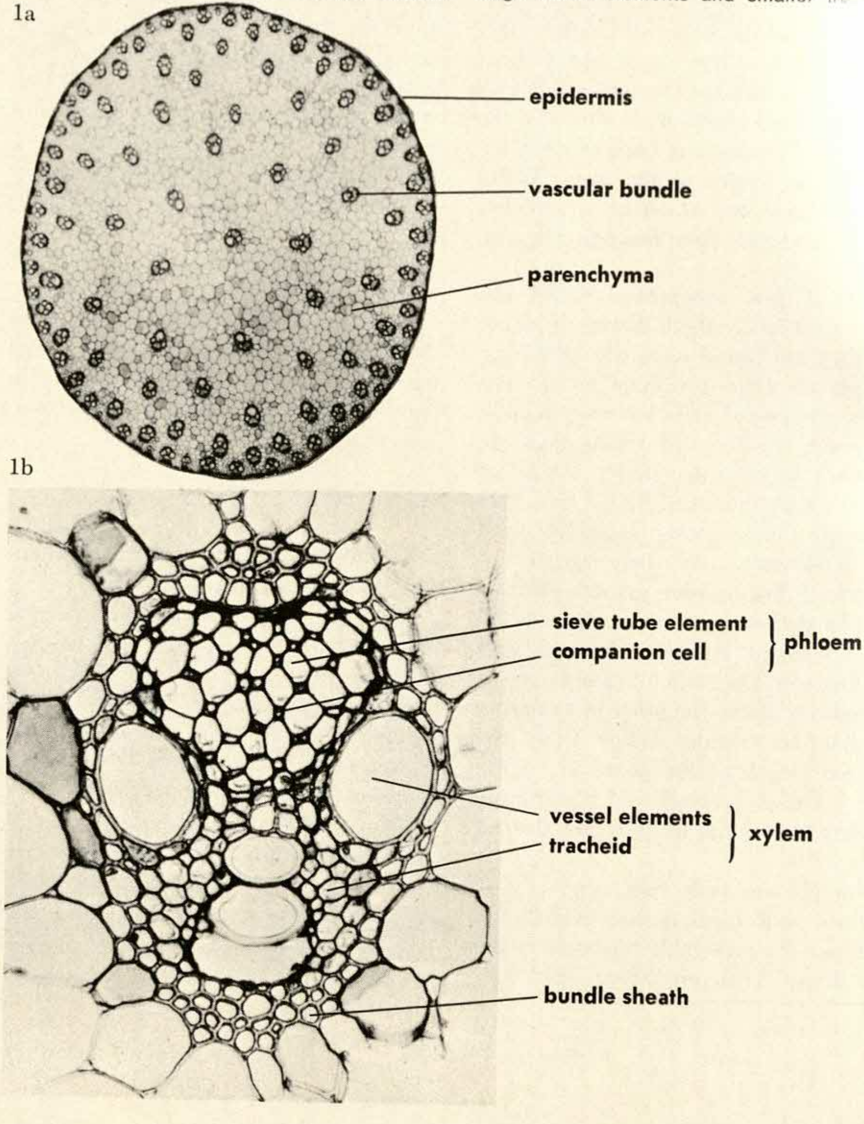
DICOT STEMS

The stems of annual dicots and the young stems of biennial and perennial dicots have the same tissues as those of monocots. They differ primarily in the arrangement of the vascular bundles, which usually are confined to a single ring near the outside of the stem. The portion of the stem inside the ring of vascular bundles is occupied by pith, while the portion outside the ring is occupied by cortex and a single layer of epidermal cells. All of these are primary tissues.

In stems that live more than one growing season, a single layer of peristematic cells—a layer known as vascular cambium—lies between the primary xylem and primary phloem in the vascular bundles and between the pith and cortex. When vascular cambium cells divide, they produce secondary xylem cells and secondary phloem cells. Ordinarily much more secondary xylem is formed than secondary phloem. Secondary xylem comprises the wood of trees and shrubs, and secondary phloem comprises some of the bark.

Five types of xylem cells exist in angiosperm wood. Two of them conduct water vertically in the stem and contribute to the strength of the stem. Tracheids and vessel elements are thick-walled, functional, nonliving cells. They are cylindrical and the tracheids are longer and narrower than the vessel elements. A third type of thick-walled nonliving cell is the xylem fiber. Superficially it resembles the tracheid, but it is somewhat narrower and longer. It does not conduct water; its function is that of strengthening the stem. Xylem rays consist of thin-walled, living cells that conduct water

MONOCOT STEM—This cross section of a corn (*Zea mays*) stem (Illustration 1a) shows the scattered arrangement of vascular bundles that is typical of monocot stems. Illustration 1b shows that each vascular bundle contains both primary phloem and primary xylem surrounded by a bundle sheath. The phloem contains sieve tube elements accompanied by smaller companion cells. The xylem has a few large vessel elements and smaller tracheids.



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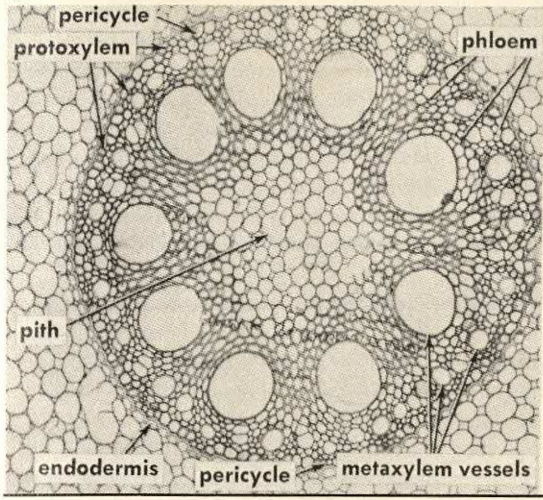

MONOCOT ROOT—Corn (*Zea mays*) has the typical anatomy of a monocot root. The center is occupied by pith. Around the pith are several groups of primary xylem cells; the first of these to differentiate are called protoxylem, and the last to differentiate are called metaxylem. The primary phloem consist of groups of very small cells alternating with the groups of primary xylem cells. The pericycle appears as an inconspicuous circle of very small cells, but immediately beyond it is the endodermis, the cells of which have extremely thick walls on their inner and lateral walls. A large cortex surrounds the endodermis; most of the cortex and the epidermis are not shown here.

laterally through the wood. Xylem parenchyma cells are also thin-walled, living cells that store food in the xylem.

The sizes of the various cells of the wood depend in part on the time of the year in which they were formed. The vascular cambium lays down large cells in spring and smaller cells in summer. During the growing season the size of successively formed xylem cells gradually decreases. During the winter the cambium is dormant, and no new xylem cells are formed. Activity is renewed the following spring. Because of this, growth rings are visible in the wood. A good estimate of the age of the tree can be made by counting the number of growth rings in the wood at the base of a tree trunk.

Angiosperms possess five types of phloem cells. The only one that transports food vertically in the stem is the sieve tube element, a living cell that has lost its nucleus. The sieve tube element is closely associated with small companion cells that have nuclei believed to regulate activities of the sieve tube element cytoplasm. Phloem rays conduct food laterally and they are continuous, through the cambium, with the xylem rays.

Phloem parenchyma cells and phloem fibers resemble their counterparts in the

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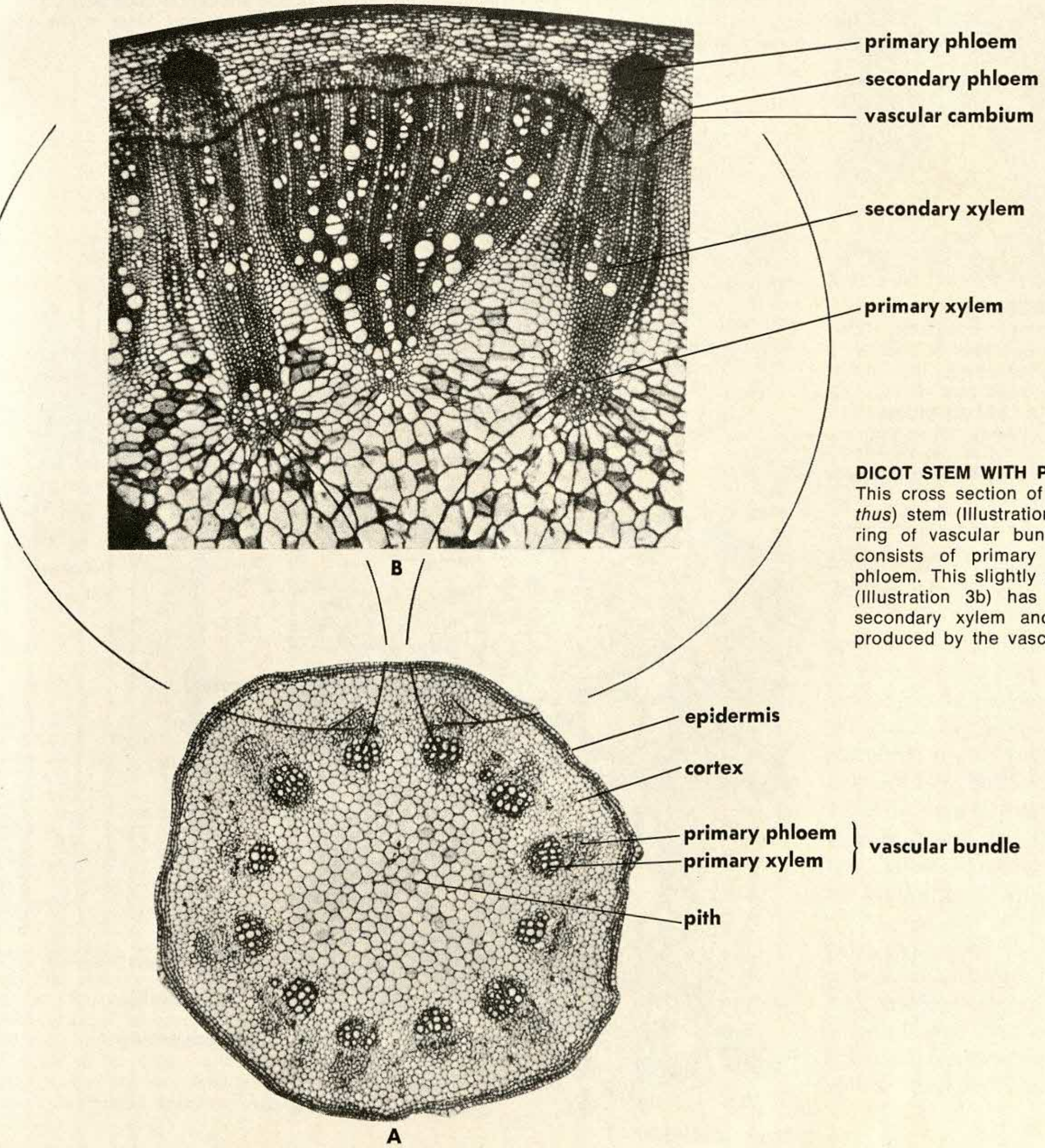

DICOT STEM WITH PRIMARY GROWTH—This cross section of a sunflower (*Helianthus*) stem (Illustration 3a) shows a single ring of vascular bundles, each of which consists of primary xylem and primary phloem. This slightly older sunflower stem (Illustration 3b) has a small amount of secondary xylem and secondary phloem produced by the vascular cambium.

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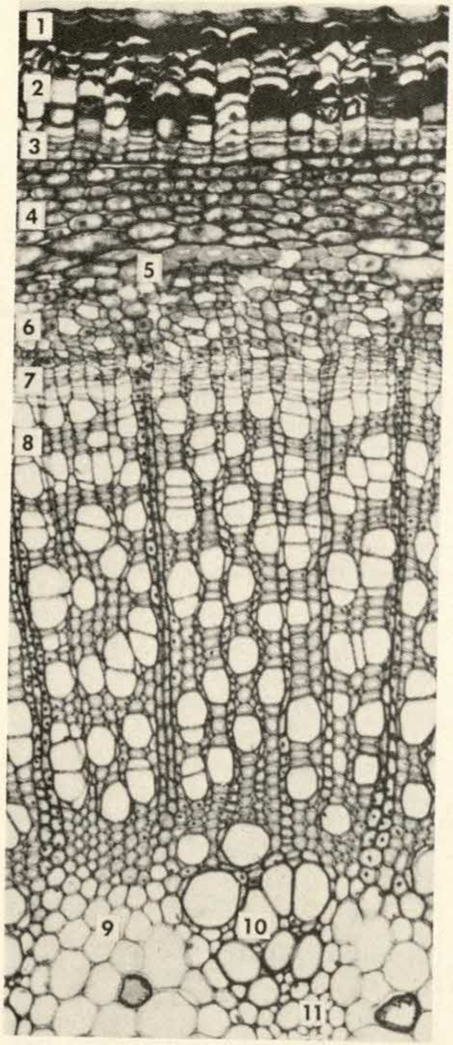

DICOT STEM WITH SECONDARY GROWTH—This is a cross section of a young elder (*Sambucus*) stem with its first year of secondary growth. (1) Crushed epidermis that would slough off in a slightly older stem; (2) cork; (3) cambium; (4) cortex; (5) primary phloem with thick-walled phloem fibers; (6) secondary phloem; (7) vascular cambium; (8) secondary xylem; (9) pith; (10) metaxylem and (11) protoxylem of the primary xylem.

xylem. With the exception of the phloem fibers, all phloem cells are thin-walled, living cells.

A second cambium, the cork cambium, forms in the outer part of the cortex of the stem. This cambium is the source of cork, which is another secondary tissue. As more and more cork is produced, the epidermis is forced off, and the cork becomes the outermost tissue of older stems. The cell walls contain suberin, a substance impermeable to water that prevents excessive loss of water from the stem.

Bark consists of all the tissues lying outside the vascular cambium. It includes secondary phloem, primary phloem, cortex, cork cambium, and cork. In some cases, the primary phloem and the cortex become crushed and are not readily distinguishable.

DICOT ROOTS

The roots of annual dicots and the young roots of biennial and perennial dicots differ from those of monocots in only a few ways. They lack a pith, and the center of the root is occupied by a central core of primary xylem. In cross section, the primary xylem appears to be star-shaped, usually with not more than five or six arms to the star. Occasionally there may be as few as three or even two arms. The number of strands of primary phloem is the same as the number of arms possessed by the xylem, and the strands alternate in position with the arms.

Secondary growth of a dicot root occurs by means of vascular cambium and cork cambium. The vascular cambium arises between the primary xylem and primary phloem and functions as it does in the stem. The cork cambium arises from the pericycle. Because of this, the formation of more and more cork pushes the endodermis, cortex, and epidermis outward, and they soon die and disintegrate. As in the stem, cork becomes the outermost tissue.

CONIFERS

The growth of conifer stems and roots and the arrangement of their tissues is much the same as that of stems and roots of dicots. One major difference is that conifer stems and roots have fewer types of xylem cells and phloem cells. Observing the absence of vessels is an easy way to distinguish between dicot and conifer.

DICOT ROOT WITH PRIMARY GROWTH—A buttercup (*Ranunculus*) root (Illustration 5a) consists mostly of cortex. The center is occupied by a vascular cylinder, and an epidermis surrounds the cortex. The vascular cylinder (Illustration 5b) contains a central core of primary xylem that appears star-shaped in a cross section. The xylem cells are large, thick-walled, and empty. Between the rays of the xylem are the groups of primary phloem with smaller, thin-walled, living cells. A layer of pericycle and another of endodermis surround the xylem and phloem. Most of the cortical cells store starch grains.

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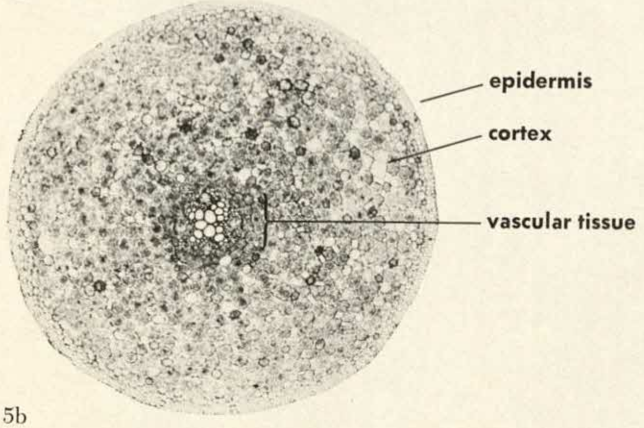

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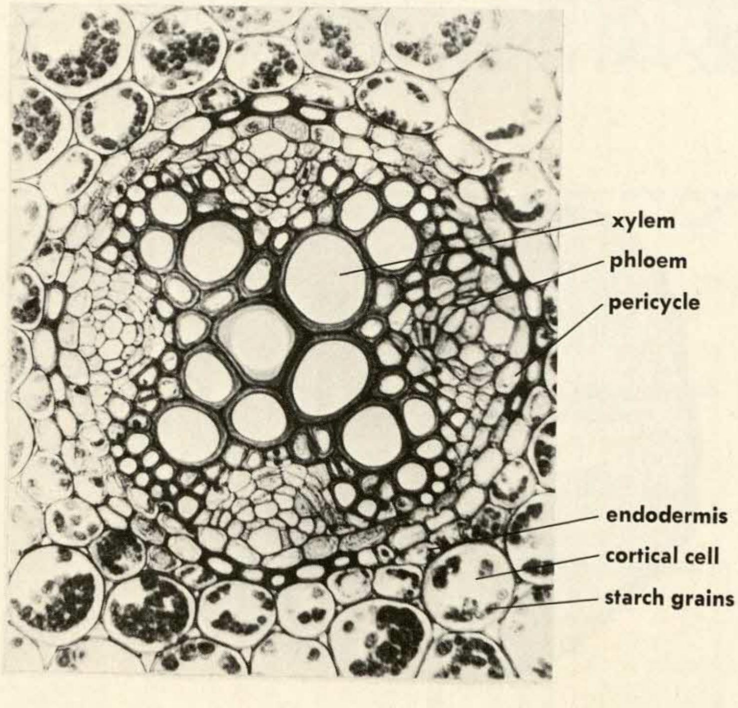

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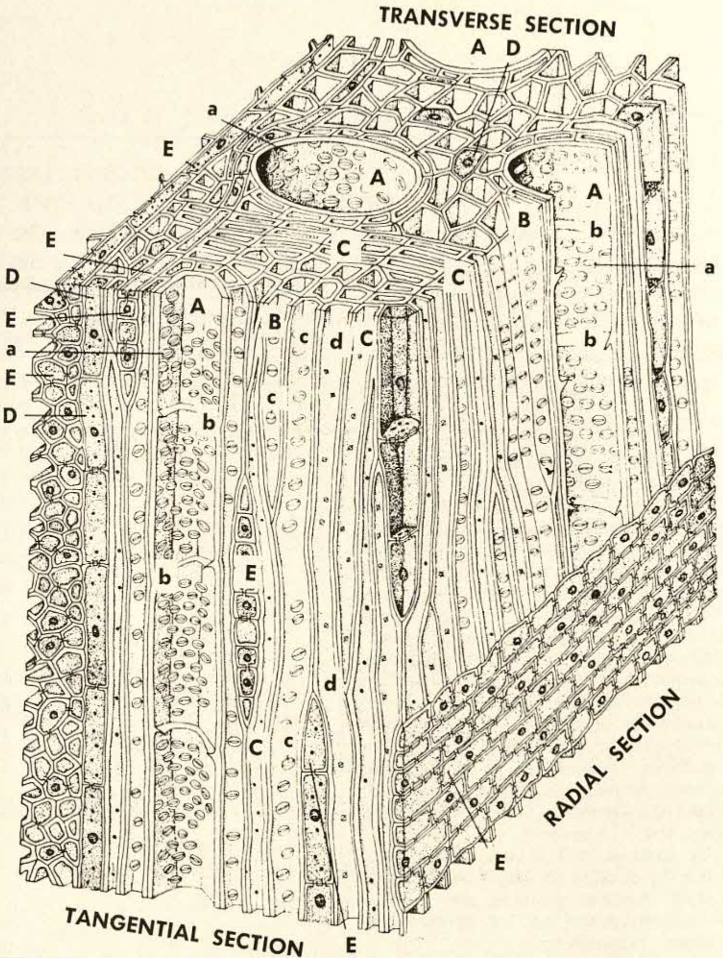
DICOT WOOD—This drawing is a three-dimensional representation of a minute, magnified portion of the secondary xylem of oak (*Quercus*). The upper surface is a cross section cut at right angles to the long axis of the stem. The radial and tangential sections are longitudinal sections cut parallel with the long axis of the stem. The radial section coincides with a radius of the stem, and the tangential section is perpendicular to the radius.

The long axes of most xylem cells coincide with the long axis of the stem, but the axes of the ray cells are horizontal. The vessels of oak are so large that they can be seen by the unaided eye. Each vessel is a series of vessel elements, the end walls of which have disintegrated.

A indicates the vessels; **a** pits in walls of vessel elements; **b** remnants of the end walls of vessel elements; **B** tracheids; **c** pits in walls of tracheids; **C** xylem fibers; **d** pits in walls of fibers; **D** xylem parenchyma; **E** xylem rays.



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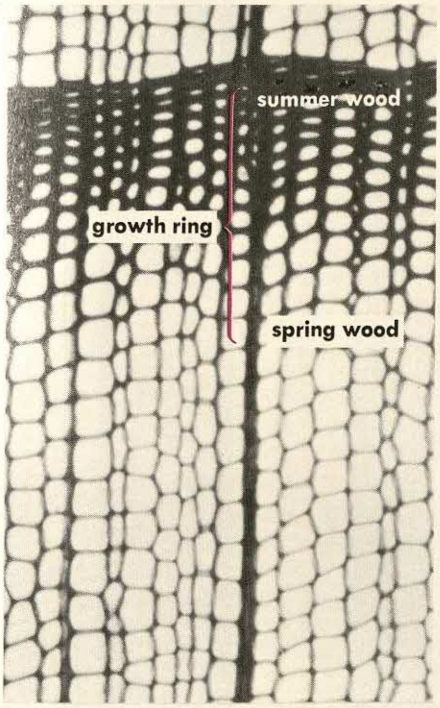
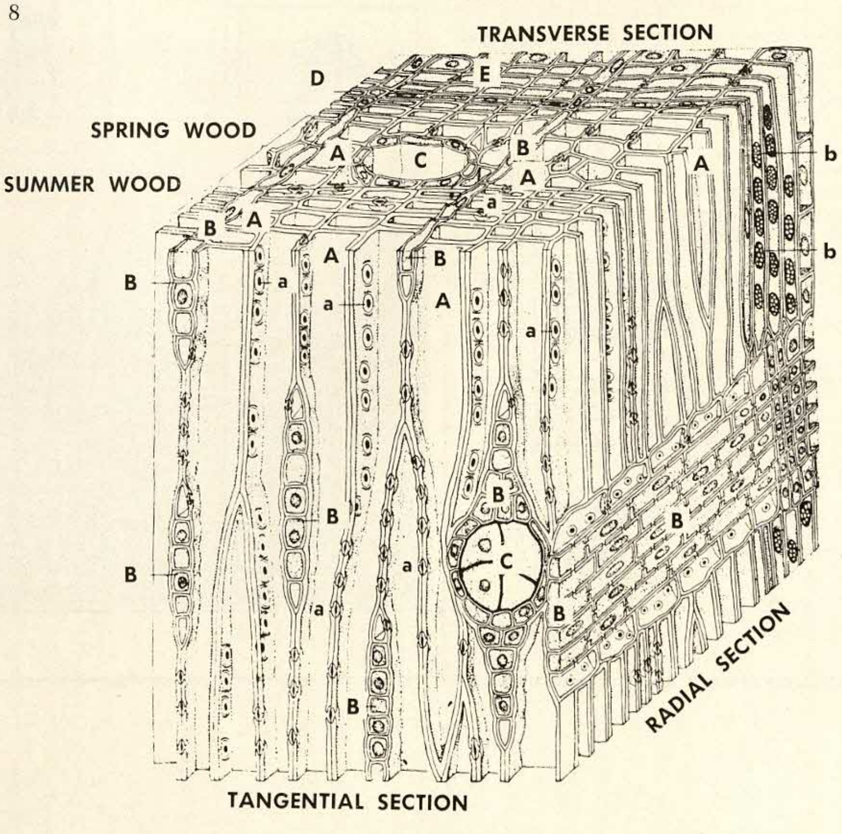


CROSS SECTION OF CONIFER WOOD—A growth ring and parts of two other rings are shown in this cross section of the wood of hemlock (*Tsuga canadensis*). The cells produced each spring are large and have moderately thick walls. Cells formed late in the growing season are very small and have thick cell walls; the hollow spaces in these cells are very small.

CONIFER STEM—Shown is a three-dimensional representation of a portion of pine (*Pinus*) stem with both secondary xylem and secondary phloem. The wood is much simpler than that of a dicot. **A** shows tracheids; **a** pits in walls of tracheid; **B** xylem ray; **C** resin canals; **D** vascular cambium; **E** sieve cells; **b** sieve area in wall of sieve cell. The xylem ray along the radial surface is continuous with the phloem ray on the other side of the cambium.

8



MILK | a complete food

The only food that newborn mammals get is milk. This fact alone suggests that milk is a complete food—at least for young mammals—and that it is the most suitable source of all the nutritional elements needed during the phase of rapid growth that follows birth. The secretion of milk by the mother's mammary glands continues until her young are capable of obtaining their own food.

The chemical composition of milk produced by each species of mammal and the length of time it is secreted are correlated with the rate of growth of the young animals and with how quickly they mature and become capable of finding other food that they can digest and assimilate. Illustration 1 shows that in species with the most rapid growth rates, the concentration of nutrients in milk is highest. Among these valuable nutrients are proteins and mineral salts.

1

RATE OF GROWTH OF SOME MAMMALS—Milk constitutes the only source of nourishment for very young mammals and furnishes them with all necessary nutrients during the phase of intense growth that follows birth. The illustration shows variations in the time necessary for some mammals to double their size from time of birth. In general, the growth rate is correlated with the concentration of nutritional elements contained in milk, especially with its protein and calcium salt content. In the milk of rabbits, which grow very rapidly, the concentration of protein is 10.4 percent and that of calcium salts 0.891 percent. In dog milk these values are 7.4 percent and 0.45 percent, respectively; in cat milk, 7.0 percent and 0.24 percent; and in cow's milk, 3.5 percent and 0.16 percent.

Man, by contrast, has a very slow rate of growth. A baby doubles its weight in 180 days. Human milk contains proteins and calcium salts in concentrations of 1.4 percent and 0.003 percent respectively.

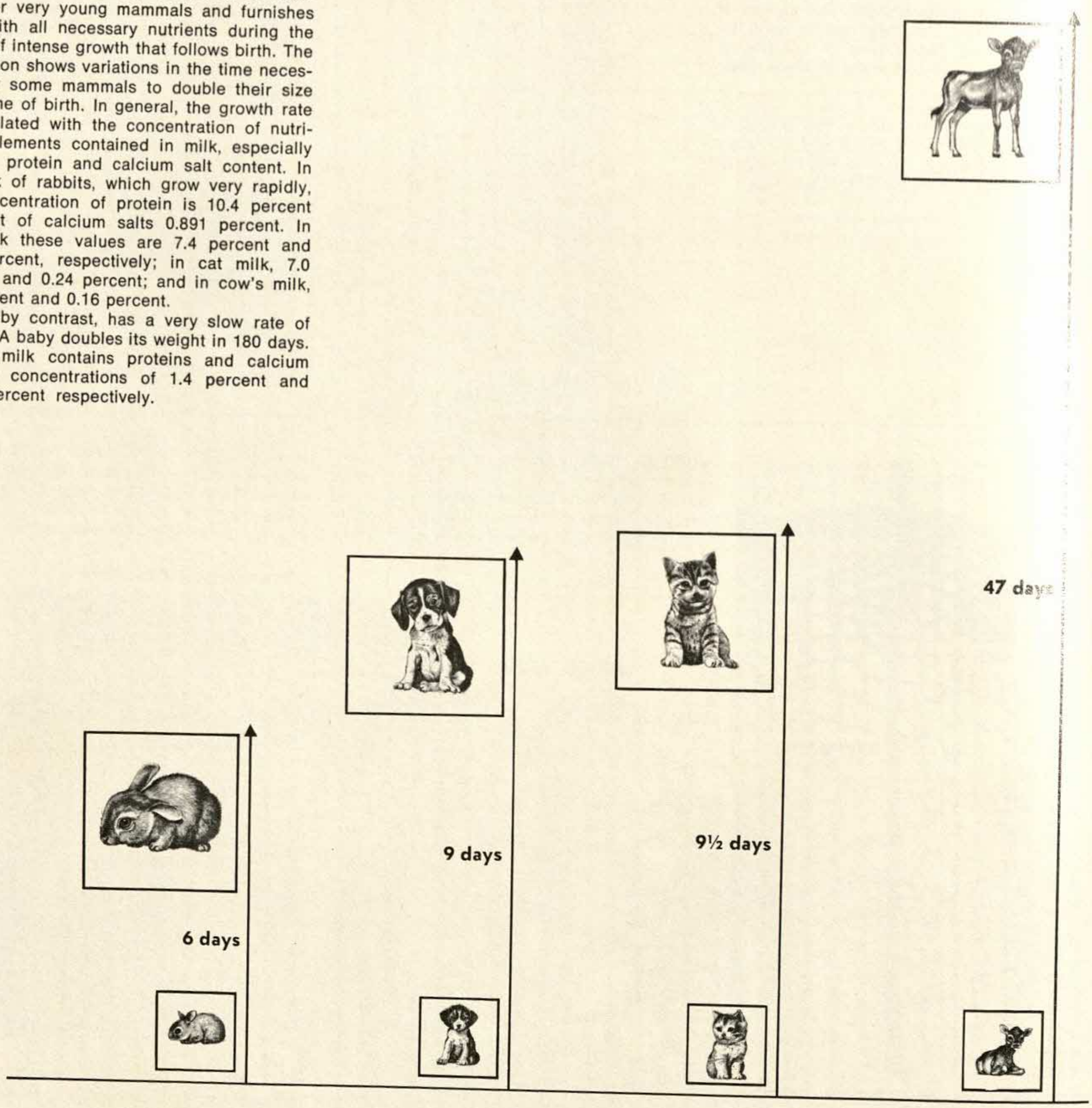
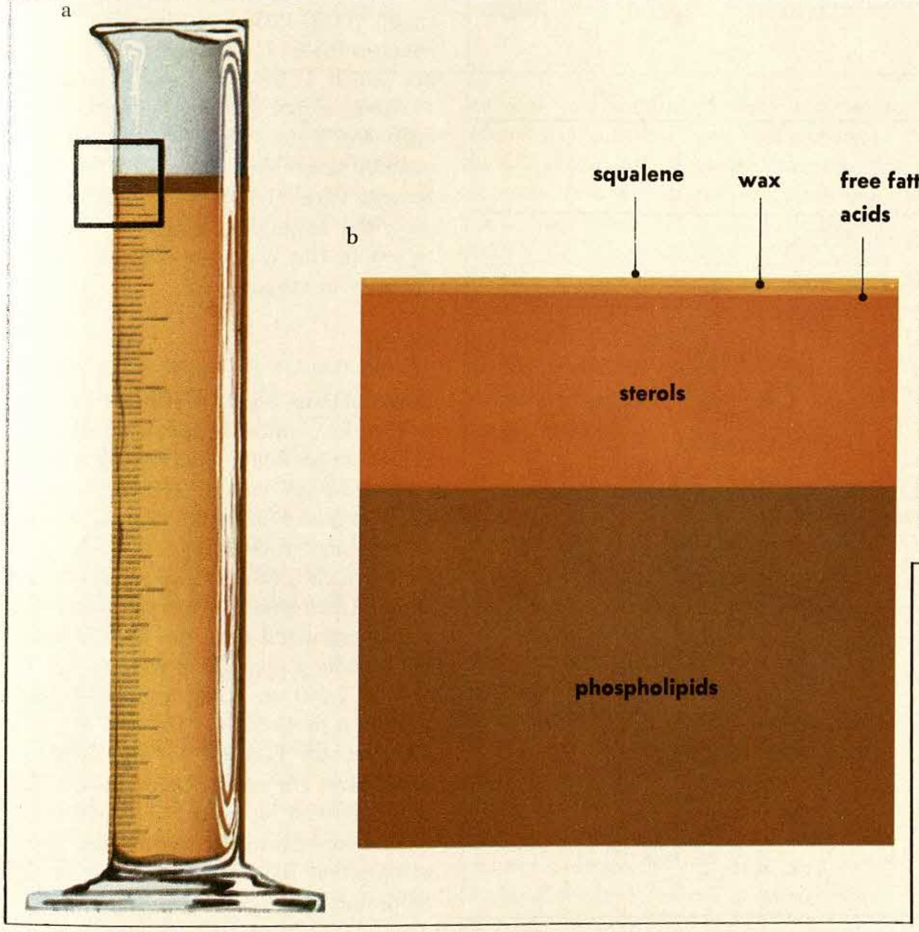


TABLE 2

AVERAGE CHEMICAL COMPOSITION, BY PERCENT, OF HUMAN MILK AND MILK OF VARIOUS ANIMALS

milk	water	solid residue	proteins			lipids	sugars	ash	specific gravity
			total proteins	caseinogen	albumin				
human	87.4	12.6	1.4	—	—	3.3	6.3	0.24	1.03
cow	87.0	13.0	3.5	2.72	0.79	4.0	4.8	0.7	1.03
donkey	86.64	10.36	2.22	0.67	1.55	1.64	5.99	0.51	1.036
goat	85.71	14.29	—	3.20	1.09	4.78	4.56	0.76	1.0305
sheep	80.82	19.18	6.52	4.97	1.55	6.86	4.91	0.89	1.0298
buffalo	81.62	18.38	4.19	—	—	7.85	4.6	0.79	—
horse	90.78	9.22	2.44	1.24	0.75	1.21	5.67	0.35	1.0347
camel	—	—	4.0	—	—	3.1	5.6	0.8	—
reindeer	—	—	10.4	8.4	2.0	17.1	2.8	1.5	—
pig	—	—	5.3	3.8	1.5	9.5	3.3	0.81	—
dog	—	—	7.4	4.8	2.6	11.6	3.2	1.3	—
cat	—	—	7.0	3.7	3.3	4.8	4.8	1.0	—
rabbit	—	—	10.4	8.2	2.2	16.7	2.0	2.5	—
rat	54.4	45.6	10.1	—	—	31.5	2.4	1.6	—

3



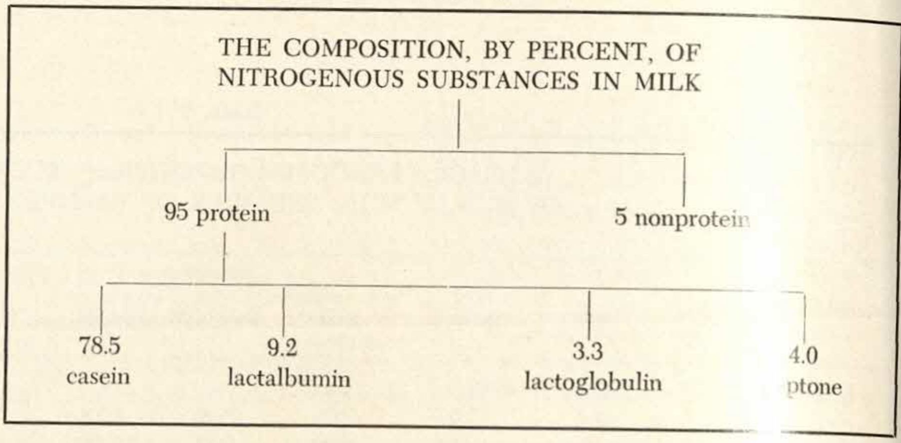
THE COMPOSITION OF THE LIPIDS IN MILK—In Illustration 3a, the yellow portion represents the quantity of fats (triglycerides) that constitute the greater part of the lipids in milk (98-99 percent). These triglycerides are made up of an average of 42.5 percent olein, 50 percent stearin and palmitin, and 7.5 percent butyrin, caproin, etc. The brown portion represents the remaining lipids and is enlarged in Illustration 3b. This group contains five different substances present in small percentages or only in traces; these are listed in Table 4.

TABLE 4

THE COMPOSITION OF THE LIPIDS IN MILK

triglycerides	98-99
phospholipids	0.2-1.0
sterols	0.2-0.4
free fatty acids	traces
ash	traces
squalene	traces

TABLE 5



Because of its rich chemical composition, milk is a nutritious food not only for babies, but for people of all ages. Since ancient times man has taken advantage of the natural phenomenon of lactation by utilizing the milk of his domestic animals. He developed in the females of these animals a tendency to produce more milk than was necessary for the needs of their young. Such careful breeding has resulted in domestic animals whose milk production is remarkable. Although the goat is capable of producing proportionally more milk for its size than any other animal, cow's milk is more widely used throughout the world. Table 2 shows the principal differences in the chemical composition of the milk of several animals, these differences are especially interesting when compared to the composition of human milk.

COW'S MILK

Cow's milk, because of its wide use, merits a detailed description in terms of physical properties and chemical composition. Its physical properties include its density, which at 15° C ([illegible] F) is between 1.029-1.033; its freezing point, which is 0.546° C (about [illegible]); and its pH, which, at 6.60, is nearly neutral.

The principal chemical constituents of milk are water, proteins, sugars, fats, mineral salts, and vitamins. The water content varies between 87 and 91 percent; the remaining substances are dissolved in the water or exist as minute particles in suspension.

FATS

Milk contains about 4 percent fat in a state of fine emulsion; that is, in the form of minute particles, each having a diameter of 3-5 μm (about .00012-.0002 in.). Each milliliter of milk contains from 2 to 6 million of these particles. Fats rise to the surface of standing milk, forming cream. Once cream is formed, the fat can be homogenized with the milk by placing it under a pressure of 200-250 kg/cm^2 (about 2,840 to 3,560 psi) after preheating it to 40-50° C (104-122° F). The fat particles become evenly dispersed throughout the milk. After homogenization, milk can no longer be separated to form cream and thus has a more stable composition than whole milk. It is also more appetizing and digestible.

TABLE 6

COMPARISON BETWEEN THE ESSENTIAL AMINO ACID CONTENT OF PROTEINS RECOMMENDED BY FAO AND THAT OF COW'S MILK

		g amino acids per 100 g of protein	
		FAO recommendation	cow's milk
isoleucine		4.2	6.4
leucine		4.8	9.9
lysine		4.2	7.8
phenylalanine		2.8	4.9
sulfur-containing amino acids	total	4.2	3.3
	methionine	2.2	2.4
threonine		2.8	4.6
tryptophan		1.4	1.4
valine		4.2	6.9

TABLE 7

VITAMINS IN MILK

Fat-soluble vitamins	
vitamin A	20 IU/g of fat
	9 mg/g of fat
carotene	5 mg/g of fat
vitamin D_3	1 IU/g of fat
vitamin E (tocopherol)	28 mg/g of fat
vitamin K	25 Dam-Glavid units/g of fat

Water-soluble vitamins per 100 cc of milk		
ascorbic acid (vitamin C)	2	mg/100 cc
biotin	3.5	μg/100 cc
choline	13	mg/100 cc
folic acid	0.8	μg/100 cc
total inositol	13	mg/100 cc
nicotinic acid (niacin)	85	μg/100 cc
pantothenic acid (Vitamin B_3)	400	μg/100 cc
pyridoxine	37	μg/100 cc
total riboflavin (vitamin B_2)	139	μg/100 cc
total thiamine (vitamin B_1)	42	μg/100 cc
vitamin B_{12}	0.3	μg/100 cc

1 μg = 1 millionth of a gram

The fats that rise to the surface of whole milk can be separated by centrifugation to produce skim milk, which contains only 1.1 percent fat. By subjecting the milk to further centrifugation, an almost completely fat-free milk can be obtained, with cream as a by-product. Butter is obtained from the cream by beating it and working it by hand or with special machines. It contains up to 87 percent fat and no more than 16 percent water.

Milk fats are composed mainly of triglycerides (olein, palmitin, stearin, and butyrin) and large quantities of short-chain fatty acids (butyric, caproic, caprylic, and capric acid). Among other fat substances, milk contains phospholipids (lecithin and cephalin) and sterols (dehydrocholesterol and ergosterol, or provitamin D).

TABLE 8

MINERAL CONTENT, BY PERCENT, IN THE MILK OF HUMANS AND VARIOUS ANIMALS

milk	potassium oxide (K_2O)	sodium oxide (Na_2O)	chlorine (Cl)	iron oxide (Fe_2O_3)	calcium oxide (CaO)	magnesium oxide (MgO)	phosphoric anhydride (P_2O_5)
human	0.0795	0.0253	0.0468	0.0008	0.0489	0.0065	0.0585
dog	0.1382	0.0779	0.1656	0.0020	0.4545	0.0195	0.5078
pig	0.0945	0.0776	0.0756	0.0040	0.2489	0.0157	0.3078
sheep	0.0967	0.0864	0.1297	0.0041	0.2453	0.0148	0.2928
goat	0.1302	0.0617	0.1019	0.0036	0.1974	0.0154	0.2840
cow	0.1776	0.0972	0.1368	0.0021	0.1671	0.0231	0.1911
horse	0.1050	0.0140	0.0310	0.0020	0.1240	0.0130	0.1310
rabbit	0.2516	0.1980	0.1355	0.0020	0.8914	0.0552	0.9966

SUGARS

The sugar in cow's milk consists almost exclusively of lactose, and its concentration averages 4.8 percent. This sugar seems to be formed from glucose in the cells of the mammary glands of the cow. Lactose is subject to changes when milk is stored. When acted on by the lactic acid bacteria, lactose is transformed into lactic acid, which causes the milk to sour and to curdle.

PROTEINS

From the physiological point of view, proteins are one of the most important substances in milk. The proteins in milk are casein, lactalbumin, lactoglobulin, and small quantities of peptone. Casein, which is quantitatively the most important protein (it occurs in milk at a concentration of about 3.5 percent), is linked to notable quantities of phosphoric acid and calcium. Casein contains all the amino acids necessary to the development of the newborn. The coagulation of casein occurs only at a temperature of 95 to 100° C (203 to 212° F). For this reason, pasteurization, which is accomplished at 61.7° C (143° F), does not cause visible changes in milk. The other proteins in milk coagulate at 70 to 80° C (158 to 176° F).

Nutritionally, the amino acids in milk proteins are important because the nutritional value of the proteins is directly related to the amino acids that constitute them. Table 6 compares the amino acids of cow's milk with the amino acids considered necessary for an adequate human diet by the Food and Agriculture Organization of the United Nations. The table shows clearly that, with the exception of tryptophan, the proteins in cow's milk are extremely rich in essential amino acids (which cannot be synthesized by the human body).

MINERALS AND VITAMINS

Mineral salts are abundant in milk (0.7 percent), and it is interesting to note that they are found in various types of milk in the same proportion as in the bodies of the animals nourished by it. Potassium and calcium phosphates are especially important, the first for building muscles and the second for building bones, both intensely active processes in young individuals. Milk contains relatively little iron, but this is of little importance because the animal is born with an abundant iron reserve acquired from the mother's blood and stored in its own liver. Adults require other foods to obtain enough iron for their needs.

Milk is a good source of vitamins A and D, which are extremely important factors in normal growth, and of vitamin C and the B complex vitamins.

PROCESSING OF MILK

Pasteurization is a relatively mild heat treatment that destroys any pathogenic microorganisms present in milk. It preserves milk for only a few days, but it causes little change in its flavor or other characteristics. Sterilization, desiccation, evaporation, and condensation preserve milk for practically unlimited periods of time; but they modify its physical properties and chemical composition. A new process has recently been added to these now-conventional methods. It is sterilization by means of a brief exposure to steam at 160-170° C (320-338° F), and the process preserves all the properties of milk.

Since the availability of pasteurized milk, home processing by boiling is rare. Furthermore, prolonged exposure to high temperatures somewhat diminishes the biological value of milk.

TABLE 9

BIOLOGICAL VALUE OF PROTEINS IN RAW MILK AND VARIOUSLY TREATED MILK

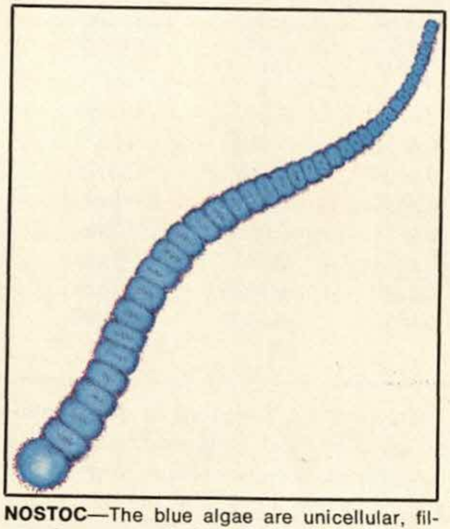
raw	84
pasteurized	84
sweet condensed	85
powdered (spray method)	84
powdered (cylinder method)	83
sterilized	79

ASEXUAL REPRODUCTION

reproduction from a single parent

Asexual reproduction, the production of new individuals from only one parent, occurs in both the animal and the plant kingdoms. It is most common among the simpler animals and plants. With the exception of the blue-green algae and many of the bacteria, most organisms that reproduce asexually are also capable of sexual reproduction. The most highly evolved animals, such as mammals, birds, and other vertebrates, do not reproduce asexually.

1

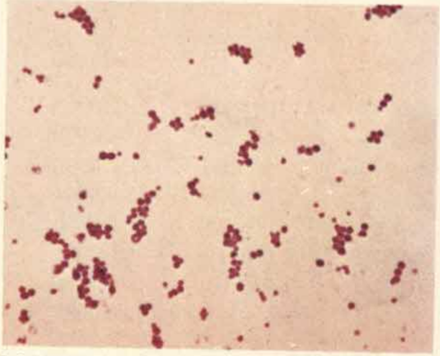


NOSTOC—The blue algae are unicellular, filamentous, or colonial forms. *Nostoc* is filamentous, and the filaments often exist in larger colonies embedded in a gelatinous mass. Reproduction is by cell division and by fragments and colonies.

No meiosis, no gametes, and no new genetic combinations are involved in asexual reproduction. The offspring are genetically identical with their single parent. Asexual reproduction alone can be of disadvantage to a species, for unlike sexual reproduction, it does not produce new genetic combinations that often are necessary for the survival of a species, especially if the environment should change greatly. However, if superior genotypes already exist, asexual reproduction can ensure the rapid multiplication of individuals with these genotypes. All of the asexually produced descendants of a single individual are genetically alike, and they constitute a clone.

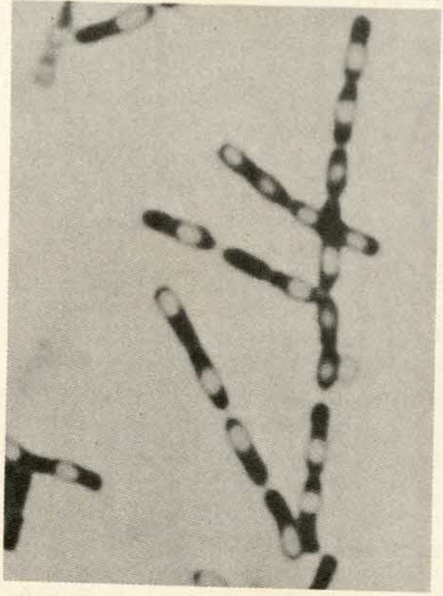
Asexual reproduction by unicellular organisms occurs simply by cell division, which may be by fission, by budding, or by the production of special asexual spores. Among multicellular organisms, there may be budding, fragmentation, or the production of special cells such as asexual spores.

2a



BACTERIA—Bacteria (Illustration 2a) reproduce mostly by fission, and they reproduce very rapidly. Within a few hours a single bacterium can give rise to a large colony. Illustration 2b shows a streptococcus, a chain of spherical bacteria.

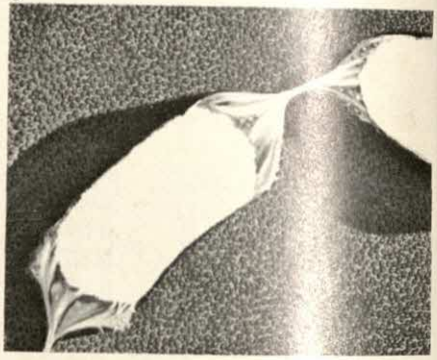
2b



FISSION

Fission is the division of a parent cell into two daughter cells of equal size. It occurs by mitotic cell divisions in most of the unicellular protozoa, algae, and fungi that have discrete nuclei. The term *fission* is also applied to the cell division of unicellular blue-green algae and bacteria, neither of which has discrete nuclei. In either case, the two daughter cells may separate from each other immediately after division, and lead independent lives. Sometimes separation is delayed until after the two daughter cells themselves have divided, and this leads to two-celled individuals. If separation is delayed until after several divisions have occurred, multicellular organisms result.

3

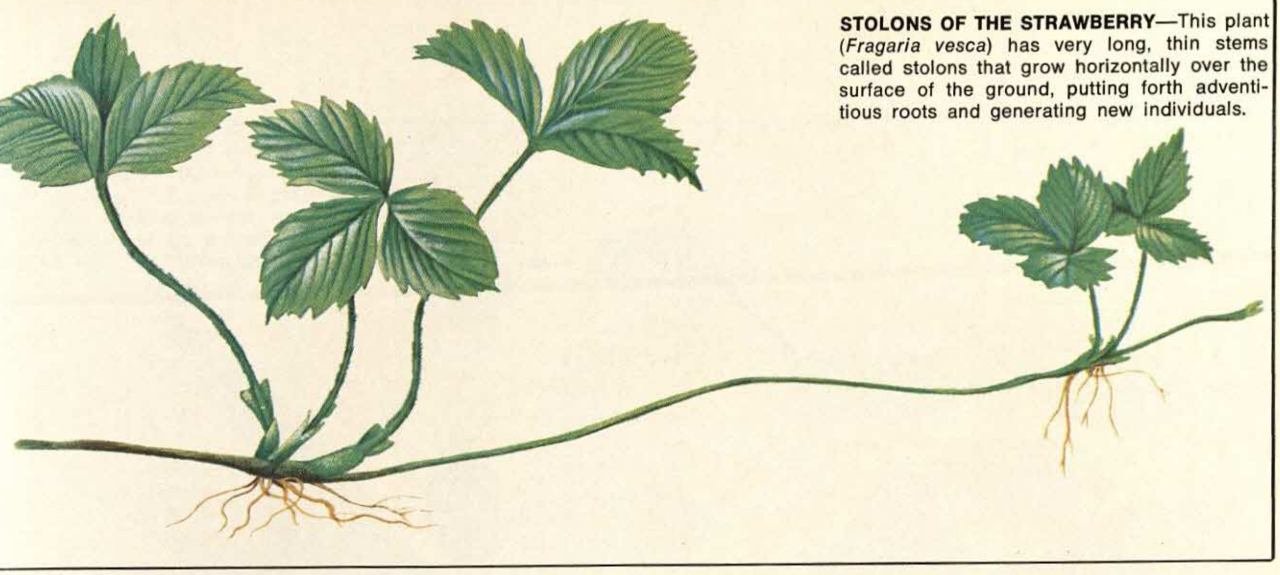


FISSION—Many unicellular organisms reproduce by fission—the division of a cell into two equal daughter cells. This illustration is an electron micrograph of bacterial cells that remained united after fission. Such organisms sometimes result from delayed separations.

BUDDING

Budding of various kinds occurs among diverse types of organisms. In yeasts, which are unicellular fungi, budding is a type of cell division in which a daughter cell originates as a small bud at the side of the parent cell. The nucleus of the parent cell divides, one of the resulting nuclei remaining near the center of

4



STOLONS OF THE STRAWBERRY—This plant (*Fragaria vesca*) has very long, thin stems called stolons that grow horizontally over the surface of the ground, putting forth adventitious roots and generating new individuals.

the parent cell, and the other moving toward the cell wall. Here a small bulge or bud appears, and the nucleus migrates into it. The bud increases in size, and a cell wall forms between the bud and the parent cell. The two cells may separate before or after the bud reaches the size of the parent cell. In some cases the parent cell may have two or more buds on it, or a partially developed bud may begin to form its own buds before it separates from the parent cell.

Among the liverworts, special multicellular buds called gemmae form on the surface of the parent plant. The gemmae are compact structures that do not look like miniature versions of the adult plant. They become detached from the parent, and if they land in a favorable environment, they germinate, eventually forming an adult plant.

Another form of budding is found in several animals of the phylum Coelenterata. *Hydra* is a relatively simple animal with a hollow, cylindrical body. At one end is a mouth surrounded by several tentacles that capture food. Occasionally a bud appears as a small mound on the side of an animal; the bud develops its own mouth and tentacles. While the new animal is still small, its central cavity is continuous with that of the parent animal. Later, tissue grows across the opening, and the bud separates from the parent and leads a separate existence.

Strobilization is a form of budding exhibited by some jellyfish which also are coelenterates. Fertilized eggs develop into larvae that swim about for a while and then settle down onto a solid substrate. Here each larva develops into a polyp which resembles a hydra. From the polyp buds off a series of medusae or jellyfish which are the mature sexual stage in the life cycle (see illustration on p. 21). Before they are released, the several medusae together resemble the cone or strobilus of a pine tree.

FRAGMENTATION

The breaking of a multicellular organism into two parts of equal or unequal size produces two new individuals. Many of the filamentous and colonial algae reproduce this way, the fragments continuing to grow by the division of their cells. Flatworms are relatively simple animals, and some of them divide into parts, each part regenerating the missing part and developing into a complete individual.

Some ferns, grasses, and other plants have horizontal stems called rhizomes if they grow beneath the ground or stolons if they grow on or above the surface of the ground. From these stems develop leaves or aerial stems that grow vertically above the ground. As the rhizomes and stolons continue to elongate horizontally, they also branch. At this point, the older parts die back and the plants fragment into separate plants at the points of branching.

Some economically important plants are propagated regularly by some type of fragmentation. Potato tubers, which are enlarged portions of rhizomes, are broken into several portions that are planted separately. As long as each piece has a healthy bud, a new plant develops. Some varieties of fruit trees, like Delicious apples or nectarines, are propagated only by grafting, which utilizes fragmentation.

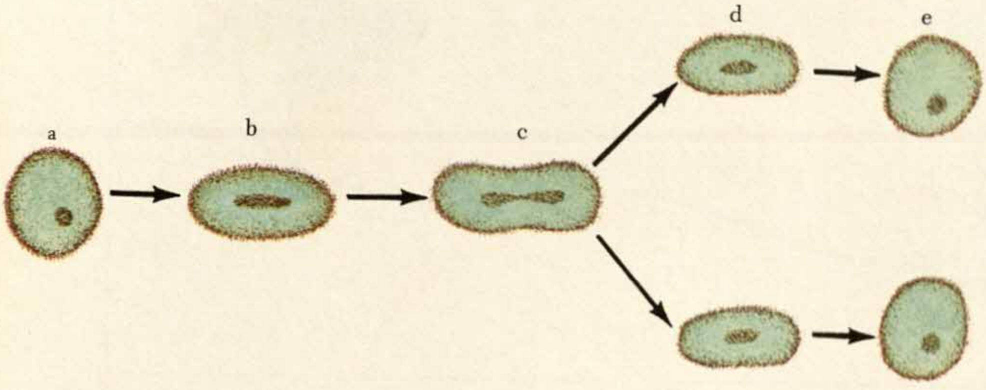
ASEXUAL SPORES

Many algae and fungi produce asexual spores, special cells that are the result of mitotic divisions, and that have, therefore, the same number of chromosomes as the parent plant. (These spores should not be confused with sexual spores, which are produced by meiotic divisions. Sexual spores are a part of the sexual life cycle.)

Zoospores are one common type of spore produced by some terrestrial fungi and many aquatic fungi (*Saprolegnia*, for example). Zoospores are motile by means of one or more flagella with which they swim through water.

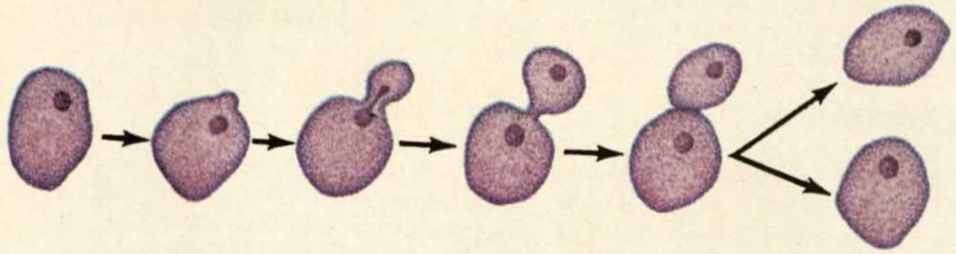
The blue-green conidiospores of *Penicillium* and the pink conidiospores of *Neurospora* give these bread molds their color because the nonreproductive portions have no pigment. The nonmotile conidiospores are produced in tremendous quantities, are disseminated by the wind, and are resistant to drying.

5



DIRECT DIVISION OF A BACTERIUM—Illustration 5 shows the stages in bacterial division. A resting, spherical cell **a** becomes elongated preceding division **b,** including the nucleus. Next, the nucleus pinches into two **c.** Two daughter cells **d** are formed by the pinching in two of the parent cell. The daughter cells **e** resemble the parent cell.

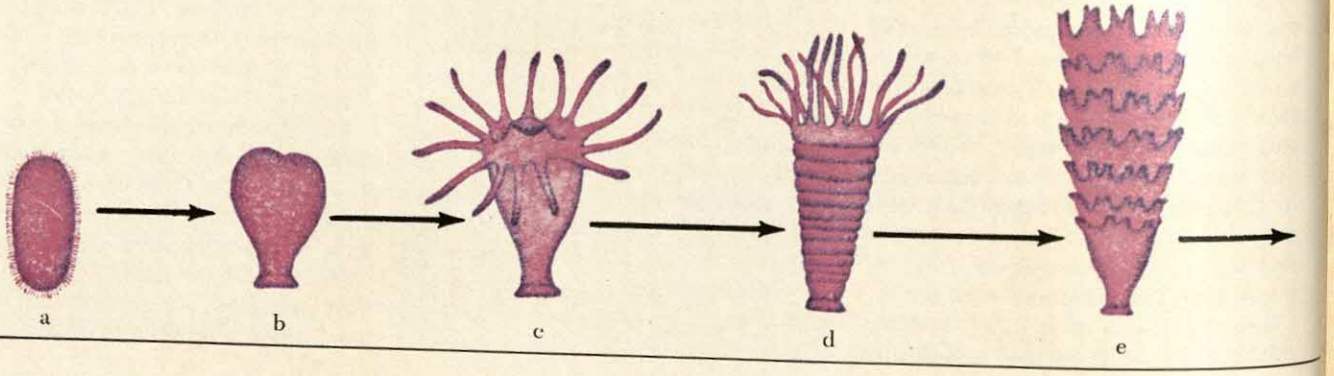
6

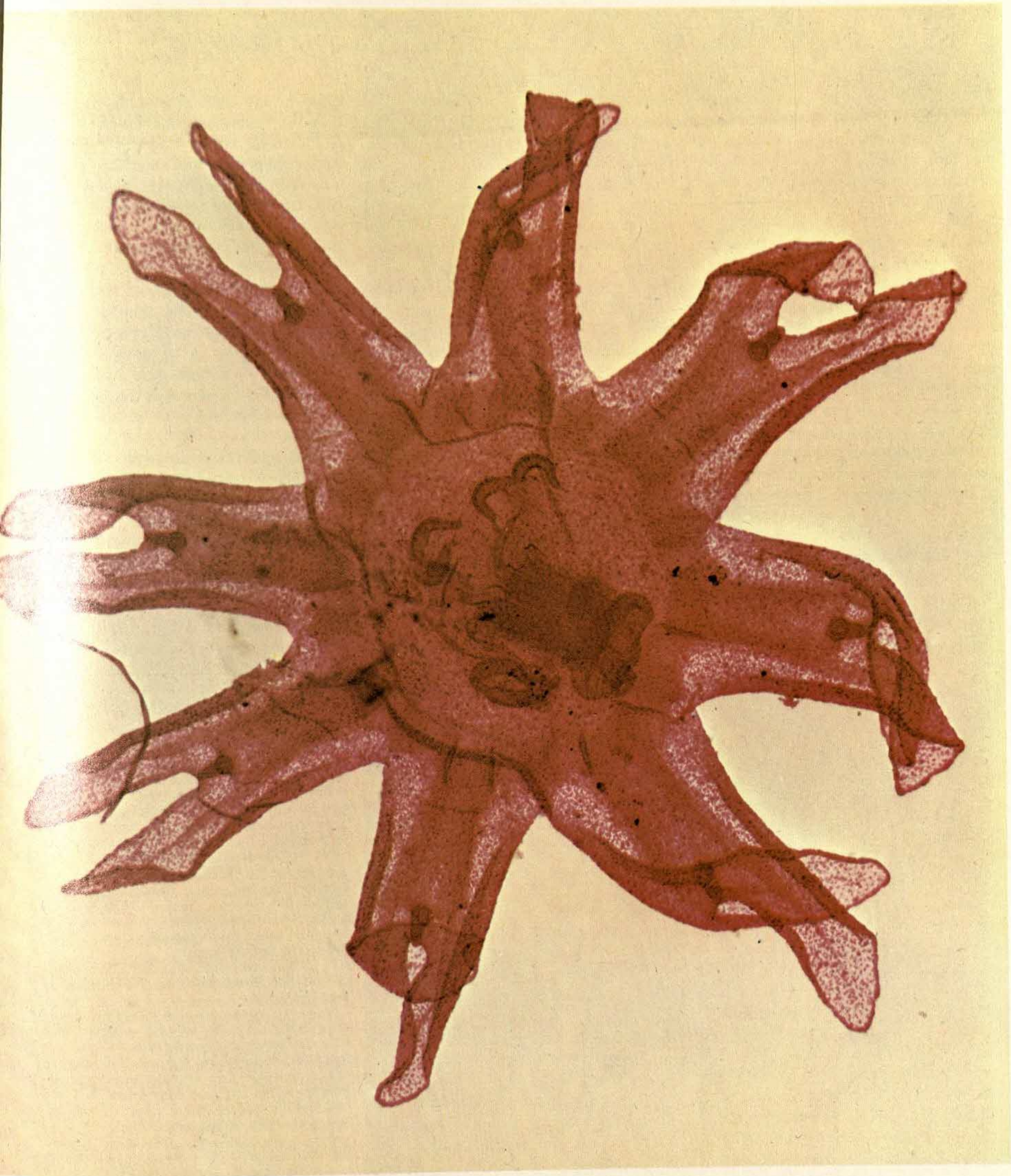


BUDDING—Asexual reproduction of yeasts, which are unicellular plants, begins with the formation of a bud at the surface of the parent cell. The nucleus divides, and one daughter nucleus moves into the bud. The bud enlarges and eventually detaches from the parent cell.

MEDUSA—The free-swimming jellyfish, or medusae, live independently. A young medusa that has recently been released is called an ephyra. (34 X)

7





DEVELOPMENT OF JELLYFISH—A swimming larva or planula **a** attaches to a substrate **b** and forms a polyp **c.** By a process called strobilization **d,e,** each polyp forms a series of immature jellyfish.

THE FAMILY TREE | a graphic system for the study of heredity

The study of human genetics is more difficult than the study of the genetics of many plants and animals. The generation time of humans is too long to permit the genetic analysis of more than a few generations in one family, for a geneticist does not live long enough to observe many generations, and few persons know the colors of their great grandparents' hair or eyes or what diseases they suffered. Furthermore, it is impossible to make the experimental crosses that geneticists make with other organisms. Most families are too small to lend themselves to statistical analysis although it is possible to pool information from many families. In spite of the difficulties, a good deal of knowledge about human genetics has been gained.

The starting point of genetic research is the determination of whether or not the characteristic under study is hereditary. The tendency of some traits to run in families suggests that they are hereditary, but they may well be caused by environmental factors that are introduced by family customs or circumstances. If all family members are thin, the thinness may be an inherited trait or it may be due to the fact that the family has insufficient food. If everyone in a family has dark skin, this may be a genetic effect but may also be caused by long exposure to sunlight. A disease prevalent in a family may be an inherited disease, or it may be a contagious disease caused by bacteria or viruses that are transmitted from one family member to another.

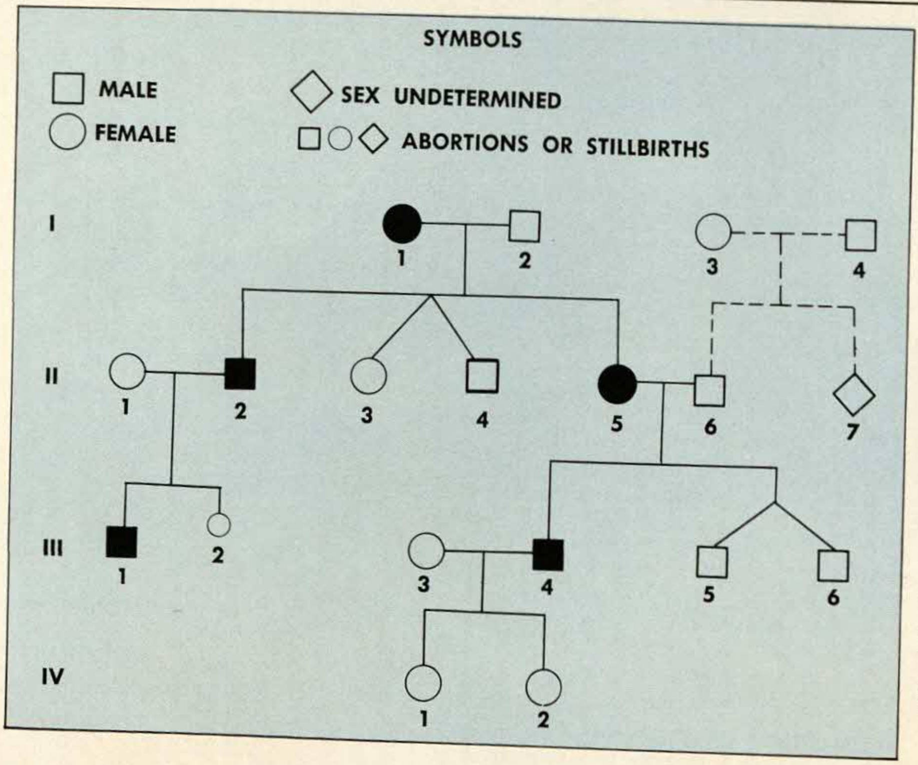
Examination of the family customs may reveal whether the trait is hereditary or environmental. Sometimes experiments—such as supplying food to a family of thin persons—are possible, but some experiments—especially those that would cause danger, financial loss, or great inconvenience—usually are not possible.

Especially valuable in the study of human genetics are identical twins who were separated shortly after birth and were raised by different families in different circumstances. Because identical twins have the same genotypes, if they differ in any traits it is quite probable that the traits were influenced by the environment rather than by heredity. Those traits that are identical in both members of many pairs of separated twins are likely to be hereditary.

USE OF THE PEDIGREE

Once it has been determined that a trait is genetic, the next step is to determine how the trait is inherited. Is it caused by one pair of genes or by several? If it is determined by a single gene, is that gene dominant or recessive? Is the gene located on an autosome or on a sex chromosome?

These questions can be answered by examining a large number of pedigrees, or family trees. Few single pedigrees provide enough information to answer the questions accurately, but the data from many pedigrees that include many marriages enable the geneticist to draw some conclusions with confidence. Each type of inheritance exhibits its own peculiar patterns over the generations, and



1

SYMBOLS USED IN A PEDIGREE—The symbol for a male is a square, and that for a female is a circle. A diamond represents an individual whose sex is not known. The symbols for a married couple are joined by a horizontal line called the marriage line. From this is dropped a vertical line connected to another horizontal line, the offspring line. The symbols for the offspring are connected to the offspring line by vertical lines. The offspring symbols are arranged from left to right in the order of birth. Illegitimate children and the irregular union that produced them are indicated by dotted lines.

A Roman numeral is assigned to each generation, and an Arabic numeral is assigned to each individual.

The symbols for twins are joined by oblique lines. If the twins are fraternal (having arisen from two fertilized eggs) as are II-3 and II-4, the two oblique lines meet at the offspring line. If the twins are identical (having arisen from the same fertilized egg) as are III-5 and III-6, the oblique lines are joined to the offspring line by a short vertical line.

Individuals having the trait being studied are indicated by solid symbols; those lacking it are indicated by hollow symbols.

these patterns are the clues that are sought and studied. The following pedigrees illustrate three of the simpler types of inheritance.

CONSTRUCTING A PEDIGREE

In the construction of a pedigree, each individual in a family is indicated by a symbol (Illustration 1). A circle is used for a female, a square for a male, and a diamond for any individual whose sex is not known to the compiler of the information. Solid symbols are used for individuals exhibiting the trait under study; hollow symbols are used for those who lack the trait.

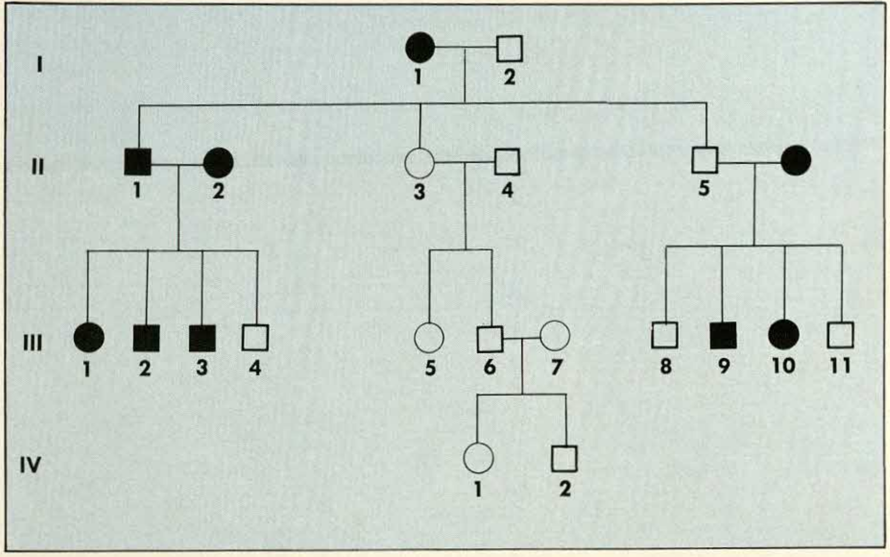
The symbols for a pair of parents are joined by a horizontal line, and below them are arranged their children's symbols. If any of the children have married, their symbols are joined to those of their spouses, and any children they have are indicated below. To permit easy reference to individuals, each generation is assigned a Roman numeral, and each individual is indicated by an Arabic numeral.

DOMINANT TRAITS

Illustration 2a shows a typical pedigree for a simple dominant trait transmitted by autosomes. One characteristic of dominant traits is that they do not skip generations. If an individual has a dominant trait, then one or both of his parents had it. If both parents lack the trait, then none of their children will have it, as, for example, individuals II-3 and II-4 and their offspring. Not all of the children of parents with dominant traits need have these traits, however, for the parents may be heterozygous, as are II-1 and II-2.

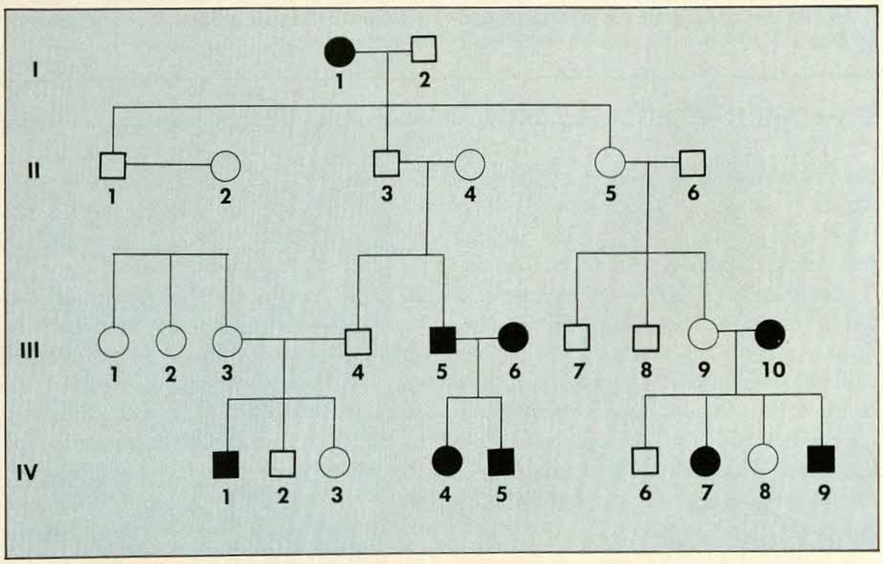
Some dominant traits in humans are brachydactyly, a condition in which the fingers or toes are abnormally short because they lack a joint; syndactyly, in which two or more fingers or toes are fused together; and glaucoma, a form of blindness caused by increased pressure within the eye. Blood types A and B are each dominant to blood type O, and Rh positive blood type is dominant to Rh negative blood type.

2a



PEDIGREES OF DOMINANT AND RECESSIVE TRAITS—Illustration 2a shows a pedigree containing a typical pattern of inheritance of an autosomal dominant trait. The pedigree in Illustration 2b shows a typical pattern of inheritance of an autosomal recessive trait.

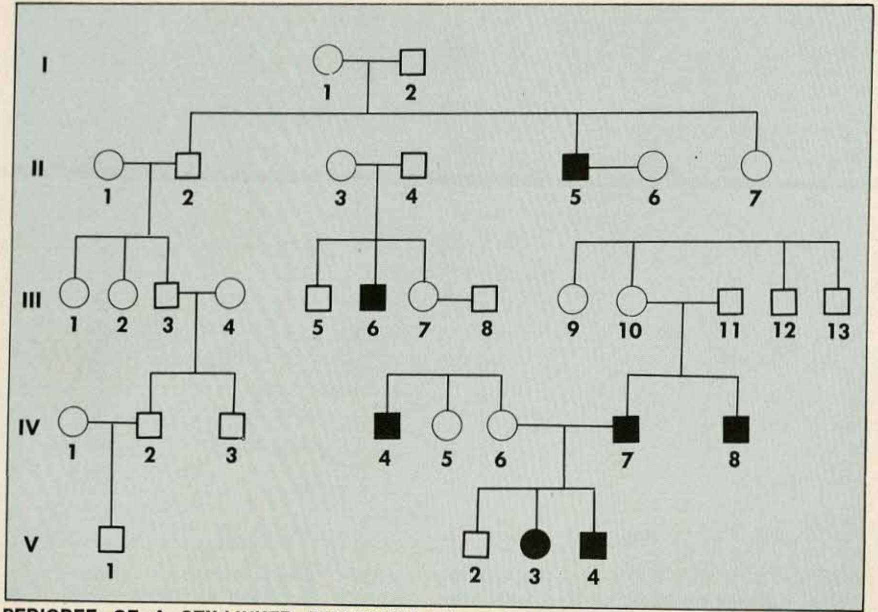
2b



RECESSIVE TRAITS

Illustration 2b shows a typical pedigree for a simple recessive trait transmitted by autosomes. The skipping of generations is common in recessive traits, which often appear in grandparents and grandchildren or in great grandparents and great grandchildren but not in the intervening generations. Children possessing the recessive trait may be born to parents who lack it if the parents are heterozygous, as are III-3 and III-4. If both parents possess the trait, as do III-5 and III-6, then all their children have it too. Inbreeding, such as the first-cousin marriage between III-3 and III-4, increases the chances of producing some children with the recessive trait. The recessive traits of humans include albinism, a condition in which the skin lacks pigment, and phenylketonuria, a form of mental retardation caused by failure to metabolize the amino acid phenylalanine.

3



PEDIGREE OF A SEX-LINKED RECESSIVE TRAIT—Sex-linked recessive traits tend to skip generations as do autosomal recessive traits. However, nearly all the individuals possessing the trait are males who inherited it through their mothers. Females who possess the trait are rare, and they are always the daughters of males who possess it and of mothers who either possess it or are heterozygous for the trait.

SEX-LINKED RECESSIVE TRAITS

Sex-linked recessive traits, a pedigree of which is shown in Illustration 3, differ from autosomal recessive traits in that the genes responsible are borne on the X chromosomes. More males possess sex-linked recessive traits than do females. A male inherits the gene from his mother and not from his father, because a male receives his single X chromosome from his mother and his Y chromosome from his father. Although a father cannot pass the gene to his sons, he can pass it to his daughters.

A typical pattern of inheritance of sex-linked recessive traits is from a man to his grandsons by way of the man's daughter, who is heterozygous and thus does not exhibit the trait. Such a pattern is seen from individuals II-5 and III-10 to IV-7 and IV-8.

A female can possess a sex-linked recessive trait only if she receives a recessive gene from each parent. The second-cousin marriage between IV-6 (who is heterozygous) and IV-7 can produce such a girl (V-3). Her brother (V-4) owes his trait to his mother and not to his father.

Sex-linked traits in humans include hemophilia (bleeder's disease) and color blindness.

CONSANGUINITY AND INBREEDING

In most human societies, marriages between close relatives are forbidden by custom or law; for man is an outbreeding species. It is questionable whether the prohibition resulted from realization that incest or inbreeding is detrimental; but the ban is reasonable in view of the evidence gathered by geneticists. In normally outbreeding species, the progenies of matings in which the parents are closely related tend to be less vigorous than the offspring of unrelated parents. This is a consequence of the genetic loads of deleterious recessive genes that populations carry. A recessive gene is not particularly dangerous in the heterozygous condition; but its chances of becoming homozygous are greater in the offspring of parents who are close relatives and, therefore, have more similar genotypes. The effects of outbreeding and inbreeding on the vigor, viability, and fertility of the offspring depend, however, upon the reproductive biology of the species or the population in which they occur.

Outbreeding is not always invigorating nor is inbreeding necessarily debilitating. Self-pollination is the closest possible form of inbreeding; but this inbreeding does not progressively weaken the vigor of a wheat strain. With corn, however, the opposite is seen. Inbreeding decreases the yield, and the intercrossing of inbred lines restores hybrid vigor in the progeny. Thus, hybrid vigor, or heterosis, is apparently the normal state of a corn population, while inbreeding is the normal state in wheat.

Many individuals having hereditary diseases and malformations appear as a result of consanguinity in species and populations adjusted to outbreeding. The kind of ailment, if any, that will appear in a given offspring depends on what deleterious recessive genes were carried by the common ancestor of the relatives who mate. Studies are being made on how much inbreeding damage will occur in a given species or population.

The highest degree of consanguinity that occurs in mankind with appreciable frequency is marriage of first cousins. This results in homozygosis of 6.25 percent of the genes in the progeny. On the basis of evidence, a genetic counselor would not be justified in discouraging all marriages of people known to be relatives, but he could fairly point out that the chance of genetic weaknesses in the offspring of such marriages is measurably greater than that in the progeny of marriages between unrelated persons.

GENETIC IMPROVEMENTS

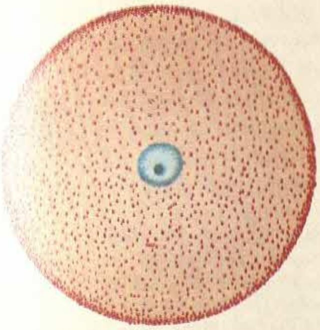
The basic method of improving crop plants and domestic animals is artificial selection. The genotypes that are selected induce in their carriers the qualities desired by the breeder. The improvement methods used in breeding must be appropriate to the reproductive biology, the genetic population structure, and the economic value of the form to be improved. Obviously it is impossible to breed as many horses or cattle as is practicable with field crops. In the choice of prized animals, breeders depend to a great extent on pedigree. Selection can operate only if genetic diversity exists; and one of the most successful means of inducing variability is hybridization—in horses or in strawberries.

GENERAL EMBRYOLOGY | the beginnings of life

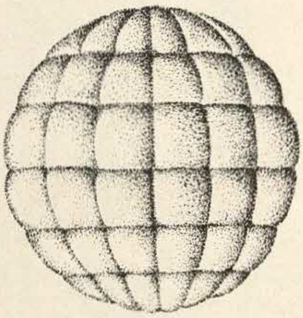
Of the many branches of biology, embryology is one that interests almost everyone because it is concerned with how animals, including man, develop from a fertilized egg. When one considers the complexity of an adult organism and recalls that all the organ systems—nervous, circulatory, digestive, and so forth—have all differentiated and grown from a single cell, the more puzzling and fascinating the embryonic processes seem to be.

DIFFERENT TYPES OF EGGS—These diagrams show different types of eggs from different species of animals. The eggs can be classified according to the amount and location of the yolk. Illustration 1a shows an isolecithal (microlecithal) egg, with a small amount of yolk evenly distributed. Illustrations 1b and 1c show telolecithal eggs with a large amount of yolk. Yolk accumulates at one end of the egg, called the vegetal pole, while the cytoplasm and nucleus are at the other, or animal pole. Illustration 1d shows the centrolecithal egg of an insect, with yolk in the middle and cytoplasm at the periphery. The amount and distribution of yolk account for the different cleavage (segmentation) patterns in different animals. Illustration 1a′ shows the total, equal cleavage that occurs in isolecithal zygotes. Illustration 1b′ shows the total but unequal cleavage that occurs in a moderately telolecithal egg. Illustration 1c′ shows that in an extremely telolecithal egg the yolk cannot cleave. A disk of cells forms on top of the yolk (discoidal or partial cleavage). Illustration 1d′ shows that in centrolecithal eggs cleavage takes place only in the peripheral cytoplasm.

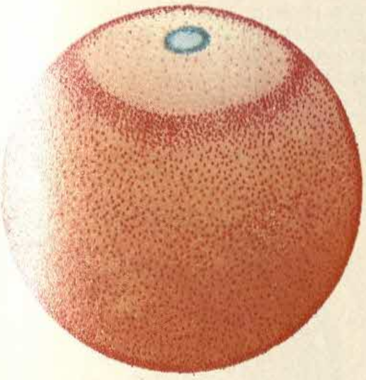
1a



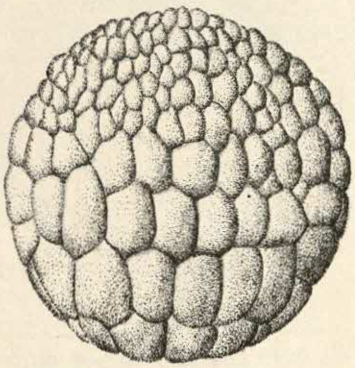
1a′



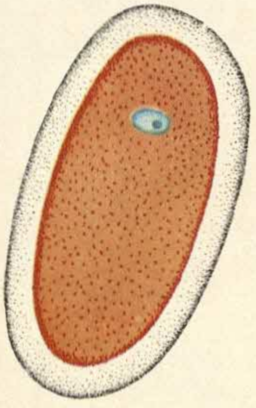
1b



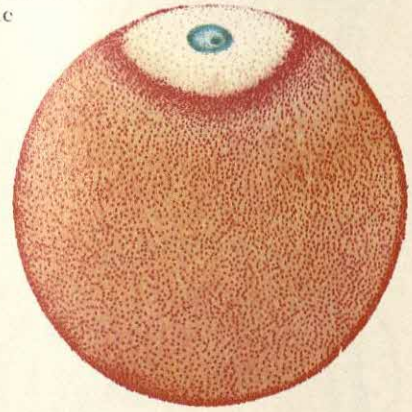
1b′



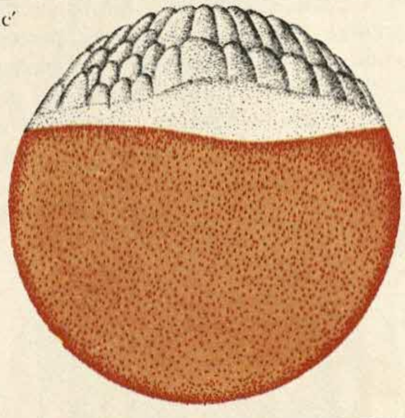
1d



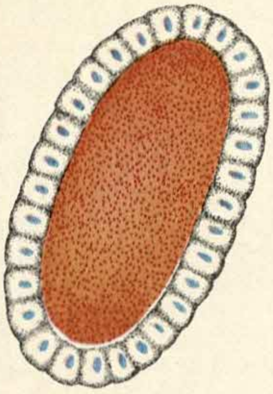
1c



1c′



1d′



Embryology can be defined as the study of development from fertilized egg to hatching, birth, or to the time the young individual can live independently of the mother. Those animals or plants that do not have embryonic stages are the single-celled organisms that usually reproduce by simple fission, forming two new organisms already like the parent; or those organisms that reproduce asexually by fragmentation or by the formation of small replicas of the adult attached for a time to the parent body, as in many species related to the jellyfish.

Within any one phylum, the development pattern is very similar, showing that all the animals or plants of that phylum are closely related. In fact, the embryonic stages resemble each other more closely than do the adult animals. A good example is found among the vertebrates, the phylum to which man belongs. The development of fish, amphibians, reptiles, birds, and mammals is very similar, particularly in the early stages. It is possible to identify a number of universal characteristics of vertebrates in an embryo only a few hours old. The main parts of the tubular nervous system, the notochord (the forerunner of the vertebral column), the pharyngeal region with its characteristic pouches bulging toward the outside of the animal and the branchial grooves or clefts projecting inward from the outside of the body (forerunners of the gill clefts)—all are easily seen in all vertebrate embryos and are considered the distinguishing characteristics of the phylum. As the embryo grows older, these structures become modified and transformed so that they are no longer as distinct and similar as they were in the earlier stages.

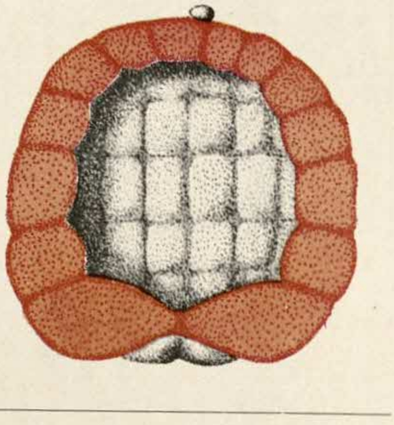
FERTILIZATION AND CLEAVAGE

Embryonic development begins with fertilization—the union of the gametes. Gamete is the general term for a sex cell, which is an egg produced in an ovary or a sperm (spermatozoon) produced in a testis. During their formation the gametes undergo meiosis, a process whose essential feature is the reduction in the number of chromosomes per gamete by one half. Because chromosomes are in pairs in all cells except mature gametes, this reduction does not mean that genes for a particular characteristic are totally lost, since at the end of meiosis each gamete contains one of each pair of chromosomes. Fertilization accomplishes two important ends: it brings together the chromosomes of egg and sperm, thus restoring the double number of chromosomes and bringing characteristics of both mother and father to the fertilized egg, and it initiates the divisions of the fertilized egg, now properly called a zygote or one-cell embryo. Mitotic divisions start almost immediately after fertilization. They are called cleavage divisions (or segmentation) and differ from ordinary mitotic divisions only in that they occur so rapidly that there is no time for the growth of the new cells before another division takes place. Cells formed during cleavage are called blastomeres; their size and shape depend on the amount and distribution of yolk in

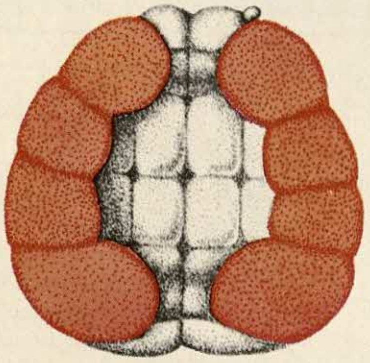
SECTIONS OF A BLASTULA OF AMPHIOXUS—Illustrations 2a, 2b, and 2c show different ages of blastulas in section. As more blastomeres form, the blastula and the blastocoel inside become larger. Blastulas form differently, depending on the amount of yolk in the egg. An amphioxus has a small amount of evenly distributed yolk (isolecithal or microlecithal).

In telolecithal eggs with a large amount of yolk, the cytoplasm is concentrated at the animal pole and the yolk is concentrated at the vegetal pole.

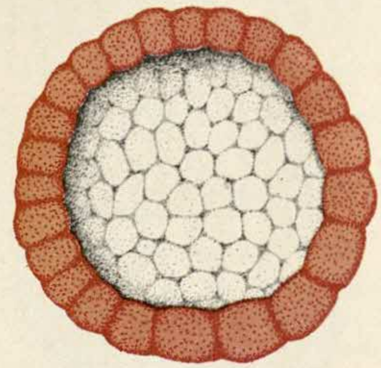
2b



2a

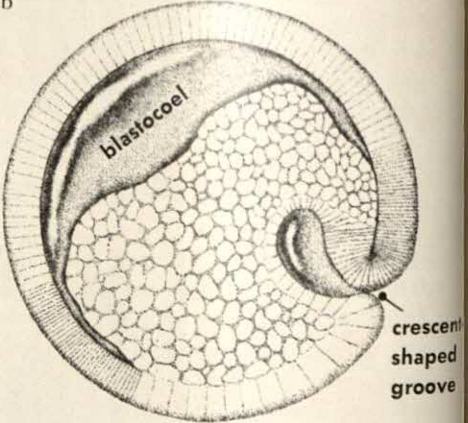


2c

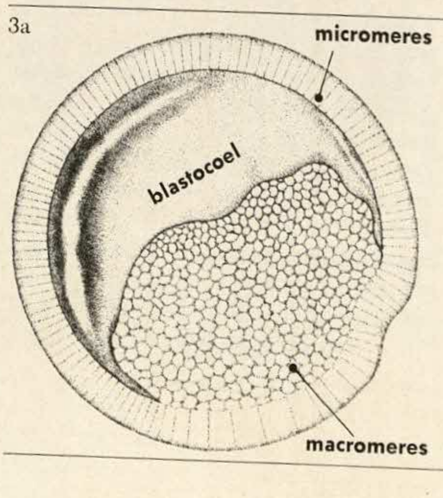


GASTRULATION IN AMPHIBIANS—Amphibian eggs have considerable yolk, so that although the egg divides completely the blastomeres thus formed are of different sizes depending on how much yolk they contain. This is called total, unequal cleavage. The small cells are the micromeres; the larger ones are macromeres (Illustration 3a). The blastocoel is smaller than in the amphioxus because the yolk-filled macromeres take up so much room. Gastrulation begins with the invagination of cells at the boundary between the micromeres and macromeres and is aided by epiboly, the downgrowth of the micromeres that helps to

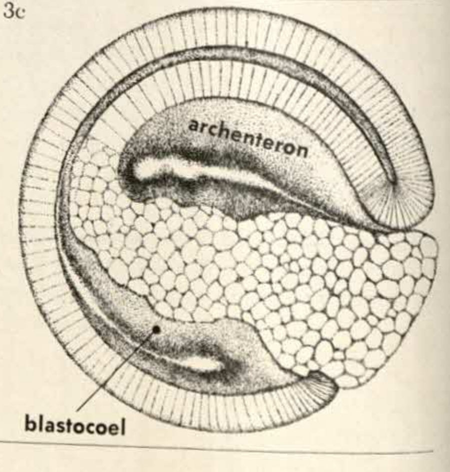
3b



3a



3c

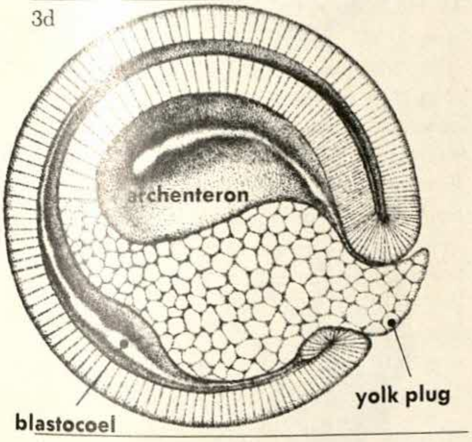


the fertilized egg.

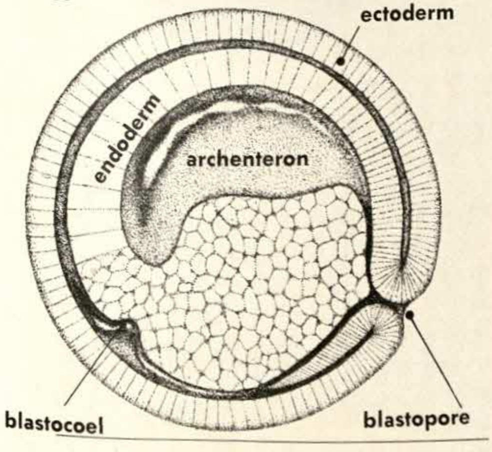
Yolk is a highly nutritious substance composed of proteins, phospholipids, and fat. Eggs with very little yolk, such as mammalian eggs, have the yolk evenly distributed in the cytoplasm and are termed isolecithal or microlecithal. In an egg having large quantities of yolk, the yolk tends to accumulate at one end of the egg, the vegetal pole. This is the condition in amphibians and to an even greater extent in reptiles and birds. Such eggs are said to be telolecithal. The amount of yolk in an egg depends on how soon the embryo can feed itself or on whether the embryo receives all its food from the mother, as in mammals. The egg of the hen is really just what is usually known as the "yolk." The so-called "egg" includes albumen, membranes, and shell—components which are not part of the egg, technically speaking. In arthropods (insects) the yolk accu-

push in the cells at the blastopore (Illustration 3b). The new cavity, open to the outside, is the archenteron, or primitive gut (Illustration 3c). The macromeres remaining on the outside at this time form a mass called the yolk plug (Illustration 3d). They too will eventually invaginate. Gastrulation forms a two-layered embryo with ectoderm on the outside and endoderm on the inside (Illustration 3d). The blastocoel is reduced in size as the archenteron becomes larger. The blastopore eventually forms the anus. At the end of the gastrulation period a third layer of cells, the mesoderm, forms between ectoderm and endoderm.

3d

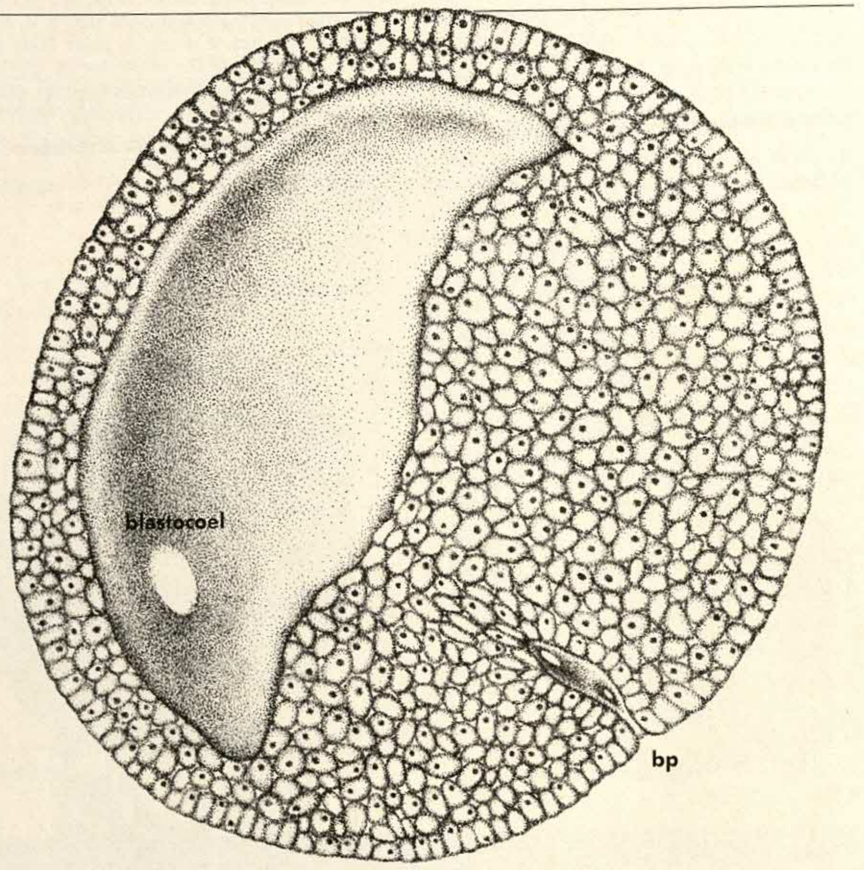


3e

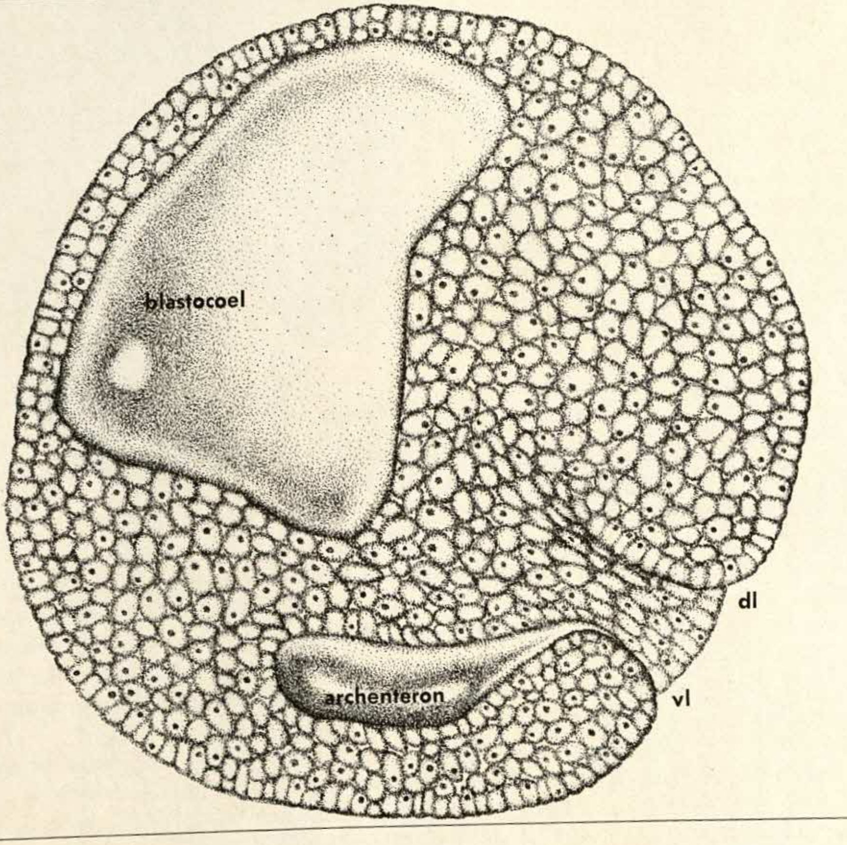


EARLY AND LATE AMPHIBIAN GASTRULA— Illustration 4a shows a sagittal section of a very early gastrula. The blastopore at this stage is a crescent-shaped groove **bp** on the outside of the embryo. Invagination and migration of cells has not yet begun. Illustration 4b shows a late gastrula with a well-formed blastopore with a dorsal lip **dl** and a ventral lip **vl.** The blastocoel becomes smaller as the archenteron (primitive gut) increases in size.

4a



4b



mulates in the center of the egg, with the cytoplasm distributed around the periphery. Such eggs are centrolecithal.

The effect of yolk is to impede or slow down cleavage; thus, it is important to know the amount of yolk in order to understand the apparently very different cleavage patterns. Because of the small amount of yolk that they contain, mammalian zygotes divide completely with the consequent formation of equal-sized blastomeres—a phenomenon known as total and equal cleavage. Amphibian eggs, which have a larger amount of yolk, also divide completely, but division goes on more readily at the animal pole where there is little yolk, and less readily at the vegetal pole where there is much yolk. This phenomenon is known as total but unequal cleavage. Reptile and bird eggs have so much yolk that cleavage takes place only in the small disk of cytoplasm (the small white dot of the hen's egg) that lies on top of the huge mass of yolk; the yolk does not divide (discoidal or partial cleavage). In all cases, the cleavage stage is over when a closely packed mass of cells is formed. This ball or disk of cells, whose number varies with the species of animal, is called a morula.

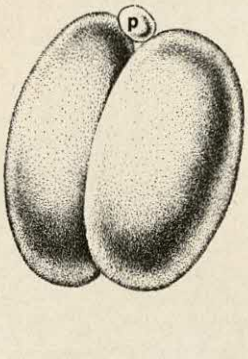
FORMATION OF THE BLASTULA AND GASTRULA

No sharp division exists between any developmental stage or period, whether it is during the embryonic time or after hatching or birth. For convenience in study and discussion, stages are designated, but often much overlapping of stages and individual variation occur. After cleavage the blastomeres shift and become rearranged so that the solid ball of cells that was the morula becomes a hollow ball in embryos developing from isolecithal or moderately telolecithal zygotes. In the case of extremely telolecithal eggs (reptiles and birds), where the morula consists of a disk of cells on top of the large mass of uncleaved yolk, the blastula is formed by the lifting of the disk of cells slightly so that a small slitlike space lies between the yolk and the embryo. The space inside the blastula (or under the blastodisc in birds) is the blastocoel.

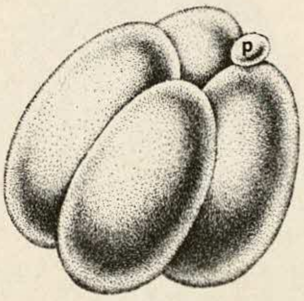
As mitotic divisions continue in blastulas formed from eggs with little or only moderate amounts of yolk, the cells become smaller and smaller. Soon some of the cells at the vegetal pole invaginate, forming a two-layered embryo, the gastrula. Gastrulas of this type look like a soft rubber ball that has been pushed in at one point. This pushing in or invagination reduces the size of the blastocoel and forms a new cavity: the archenteron or primitive gut (digestive system). The opening to the outside is the blastopore. In vertebrates the blastopore eventually forms the anus; the mouth forms somewhat later at the other end of the gastrula.

TOTAL, EQUAL CLEAVAGE—This series of illustrations shows cleavage in the embryo of the amphioxus, a very primitive fishlike vertebrate. The eggs of an amphioxus are isolecithal (microlecithal) so that cleavage is total and the blastomeres thus formed are equal in size. The fertilized egg divides into 2, 4, 8, 16 blastomeres, and so forth. A polar body **p** is visible above one of the blastomeres. This was formed during the development of the egg in the process of meiosis when the number of chromosomes was reduced one half. The polar bodies are nonfunctional and soon die.

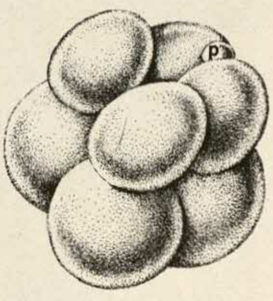
5a



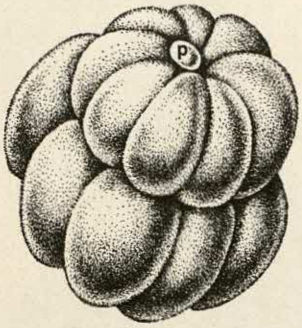
5b



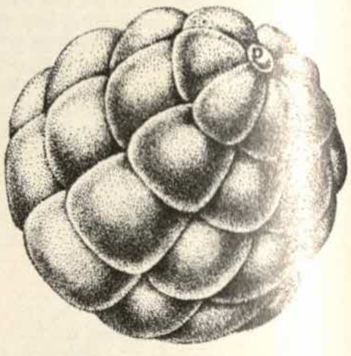
5c



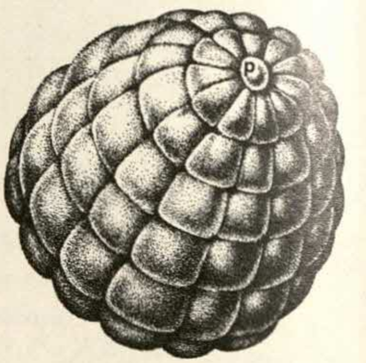
5d



5e



5f



Gastrulation in extremely telolecithal eggs is mechanically more difficult because of the large mass of inert yolk. In this case the gastrula is formed by a number of complex movements of cells, which finally make a two-layered disk from the single-layered disk that was the blastula; the upper layer is the ectoderm and the lower one the endoderm. The archenteron lies under the endoderm, with yolk beneath and a slightly curved roof of endodermal cells above. The typical gastrula is a two-layered embryo, somewhat elongated in shape.

At the close of the gastrulation period, cells begin to appear between the ectoderm and endoderm. This third layer is the mesoderm. The embryo, now consisting of several different kinds of cells, has begun to take shape. From the three layers termed the germ layers—ectoderm, mesoderm, and endoderm—all the organ systems of the body eventually will be formed.

MAMMALIAN EMBRYOLOGY

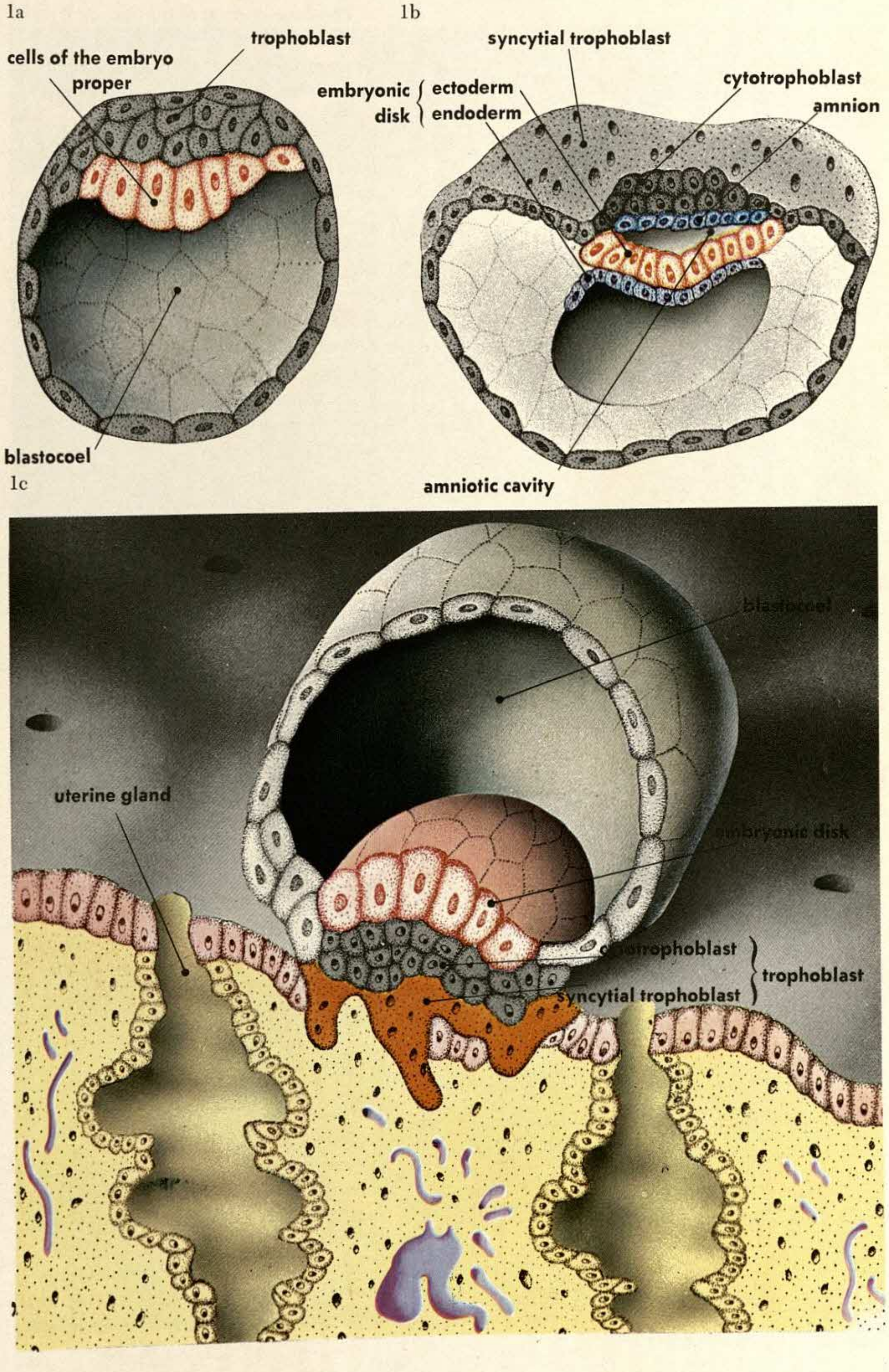
mammalian development vs the development of other vertebrates

How a human being develops from a fertilized egg into a baby is one of the most fascinating and universally appealing of all biological studies. Humans are mammals—animals whose young develop in the body of the mother, who suckle their young, and who have hair or fur on the body. Humans share common anatomical features and developmental patterns with the other mammals. In fact, in the early stages of development it is hard to distinguish one mammal from another. Furthermore, since mammals are vertebrates with many anatomical characteristics resembling those of fish, amphibia, reptiles, and birds, it is not surprising that many similarities exist between the embryology of mammals and the embryology of other vertebrates.

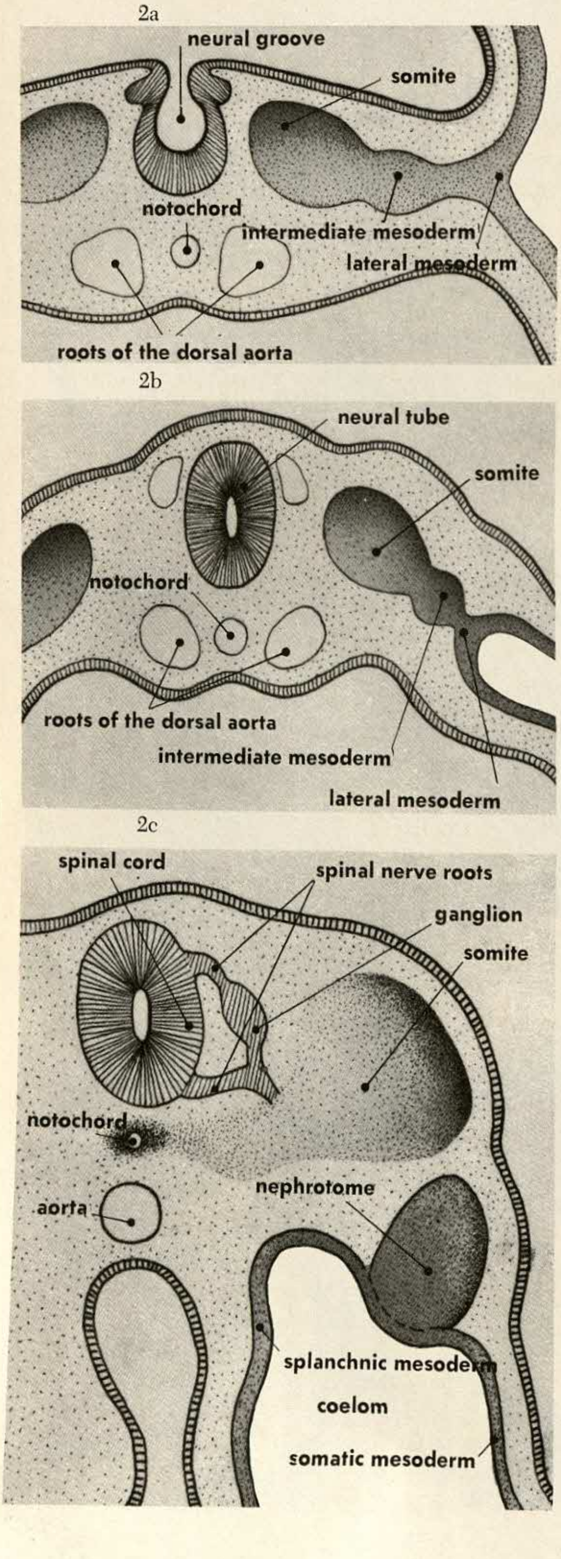
Vertebrates fall into two main groups: the aquatic (or semiaquatic) fish and amphibia and the terrestrial (air-breathing) reptiles, birds, and mammals. When, in the course of evolution, the vertebrates came out of the water, a number of anatomical and developmental problems had to be met. One of the most critical of these was how to keep the embryo from drying out if it were to develop out of water. In reptiles and birds, the evolution of shelled eggs and embryos with several embryonic membranes that prevent desiccation was one solution to the problem, while in mammals, the evolution of intrauterine development as well as retention of the embryonic membranes of reptiles and birds solved the problem. While these adaptations to development out of water obscure some of the similarities that exist in vertebrate development, a comparative study of the embryology of vertebrates shows that the basic pattern is the same.

The three subclasses of mammals show interesting differences from the reptile-bird plan of development and an increasingly close connection of the embryo and the mother. The monotremes, the subclass to which the duck-billed platypus and the spiny anteater of Australia belong, are the most primitive of the mammals. The female lays yolk-filled eggs surrounded by a leathery shell. Development, therefore, is more like that of a bird or a reptile than a mammal—except that after the young are hatched they are nourished by a milklike secretion that oozes from glands on the abdominal sur-

EARLY DEVELOPMENT AND IMPLANTATION OF THE EMBRYO—Illustrations 1a and 1b show mammalian embryos about six to eight days after fertilization. Illustration 1c shows the six-day old embryo attached to the uterine wall as the embryo begins the implantation process, which is facilitated by the sticky syncytial trophoblast on the outside of the blastocyst and by the secretions of the uterine glands. As implantation proceeds, the syncytial trophoblast digests the tissues of the uterine wall at the point of implantation.


1a
1b
1c

face of the mother. The marsupials (kangaroos, wombats, koalas), also found in Australia, have eggs with very little yolk. Their embryos develop more like those of the placental mammals except that they are born while still in an embryonic condition. These small, three-quarter-of-an-inch-long embryos have strong, well-developed front legs by which they pull themselves up and into the pouch on the mother's abdominal wall, where they continue to develop for several months. Inside the pouch, the embryos become attached to nipples that are forced into the back of the embryos' throats and held in place by the contraction of cuplike elevations that surround each nipple.



FORMATION OF THE NERVOUS SYSTEM AND BODY CAVITY—The cross sections of the embryos shown in Illustrations 2a, 2b, and 2c show how the brain and spinal cord are formed by the closing of the ectodermal neural groove. These illustrations also show that the mesoderm, laterad to the somites and kidney regions, has split into two layers. As the body wall of the embryo grows ventrally, the two mesodermal layers enclose a space, the coelom or body cavity. In Illustration 2c the digestive tube is to the left of the coelom.

The development of the placental mammals, including man, differs from that of the more primitive mammals in that the embryo completes its development in the uterus of the mother. Since the egg has no yolk, an efficient method of getting food from the mother is necessary. Other needs, such as exchange of oxygen and carbon dioxide, elimination of metabolic waste materials, prevention of desiccation, and protection, must also be taken care of. Embryonic membranes and the placenta take care of the exchanges between embryo and mother. In spite of the modifications that intrauterine development has brought about, the development of mammals follows the basic vertebrate pattern.

EARLY DEVELOPMENT OF A MAMMAL

As in other terrestrial animals, fertilization (the union of egg and sperm) takes place in the upper end of the oviduct soon after the egg has left the ovary. Since the eggs of placental mammals have almost no yolk, the zygote (fertilized egg) divides completely, into equal blastomeres. These early mitotic divisions called cleavage or segmentation stages, take place as the embryo is traveling down the oviduct (Fallopian tube). By the time the embryo has reached the uterus it is a ball of about eight cells. While this structure is free in the uterus, several more divisions take place. Finally a group of less dense cells appear, forming a layer, the trophoblast, outside an inner, denser mass of cells, the inner cell mass. The trophoblast develops into an auxiliary nutritive tissue. Most of the cells of the inner cell mass form the embryo proper. The whole ball of cells, including trophoblast and inner cell mass, is the blastocyst. The trophoblast cells secrete a fluid to the interior of the blastocyst, thereby producing a small, fluid-filled cavity and increasing the diameter of the blastocyst. The embryo is now in the blastula stage. At this time, about six days after fertilization in man, the blastocyst adheres to the uterine wall due to the sticky secretion from the trophoblast cells and to the secretions of the uterine glands. The blastocyst sinks into the soft tissue of the uterus and grows rapidly. It then becomes important to distinguish between the development of those cells of the inner cell mass that will form the embryo proper and the development of the trophoblast, and those cells of the inner cell mass that form auxiliary or extraembryonic membranes and the fetal portion of the placenta.

FURTHER DEVELOPMENT OF THE MAMMALIAN EMBRYO

The inner cell mass soon becomes a disk inside the blastocyst, with a cavity both above and below the disk. The disk, round at first, soon becomes elliptical. It is known as the embryonic shield. It has an upper layer of cells, the ectoderm, and a lower layer, the endoderm. A median thicker line of cells, the primitive streak, appears with a dense knot of cells at its anterior end. From this knot (Hensen's node) the notochord grows anteriorly. The notochord is a primitive strengthening rodlike structure that contributes to the formation of the vertebrae. The third, middle layer of cells grows laterad and anteriad from the primitive streak and Hensen's node. This middle layer is the mesoderm. The embryo is now in the late gastrula stage, with the main axes of the body determined and the three germ (germinative or formative) layers of cells beginning to form the organ systems. The ectoderm forms a neural fold that extends around the notochord and primitive streak. The edges of the fold meet in the midline to form the neural tube. As the tube is pinched off from the rest of the ectoderm, it becomes covered with epithelial ectoderm. The tube is the beginning of the central nervous system; the larger anterior end is the brain and the smaller posterior part the spinal cord. The upper or epithelial layer of the skin, including such outgrowths as hair, nails, and sweat glands, also stems from ectodermal cells. The lining of the digestive tube, the respiratory system, and all of the liver and pancreas are derived from the endoderm. The mesoderm forms the skeleton, muscles, connective tissues such as tendons and ligaments, the circulatory system including the blood, and reproductive and excretory systems.

AUXILIARY MEMBRANES AND THE PLACENTA

Since the mammalian egg has little or no yolk, food must be provided almost immediately from the mother. As soon as the blastocyst has sunk into the lining of the uterus, the trophoblast cells on the outside of the blastocyst divide, forming a large number of nuclei embedded in cytoplasm but without cell membranes. This syncytial trophoblast digests and absorbs uterine tissue, thus temporarily supplying the young embryo with food. The trophoblast soon develops villi on its outer surface, thereby increasing its digestive and absorptive area. The trophoblast with its villi has now become the chorion. It is lined with mesoderm. As the blastocyst enlarges and bulges into the uterine cavity, the chorion on the side toward the original point of implantation (embedding) forms the embryonic (fetal) part of the placenta, while the part of the uterine wall into which the now much-branched chorionic villi are embedded forms the maternal part of the placenta. The shape and intricacy of the connection between the fetal and

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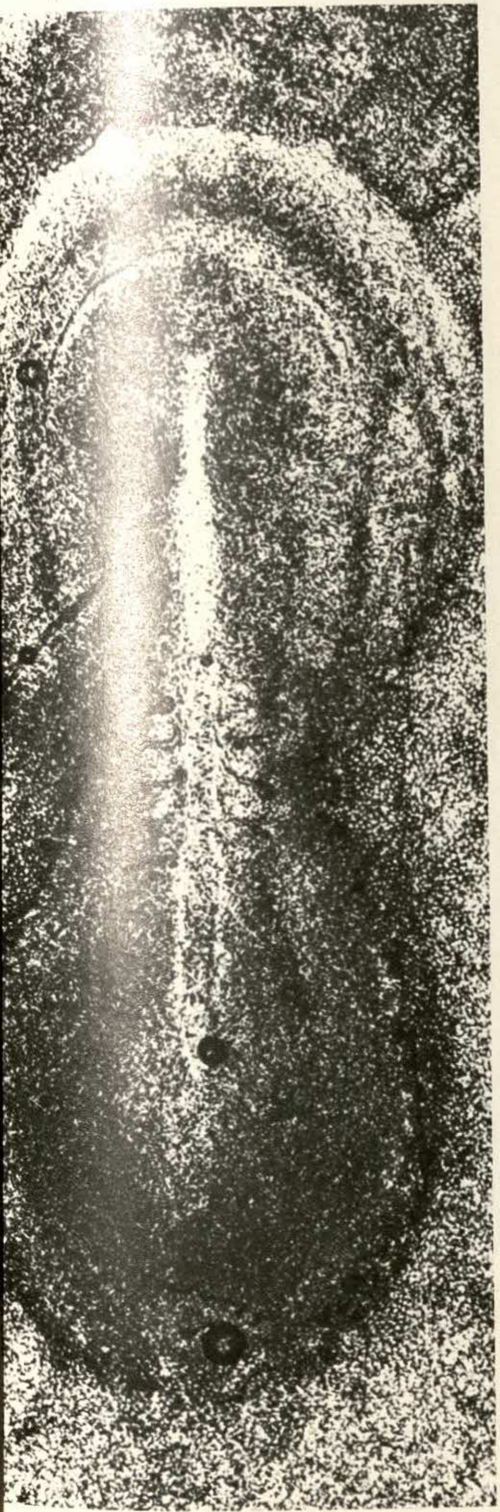
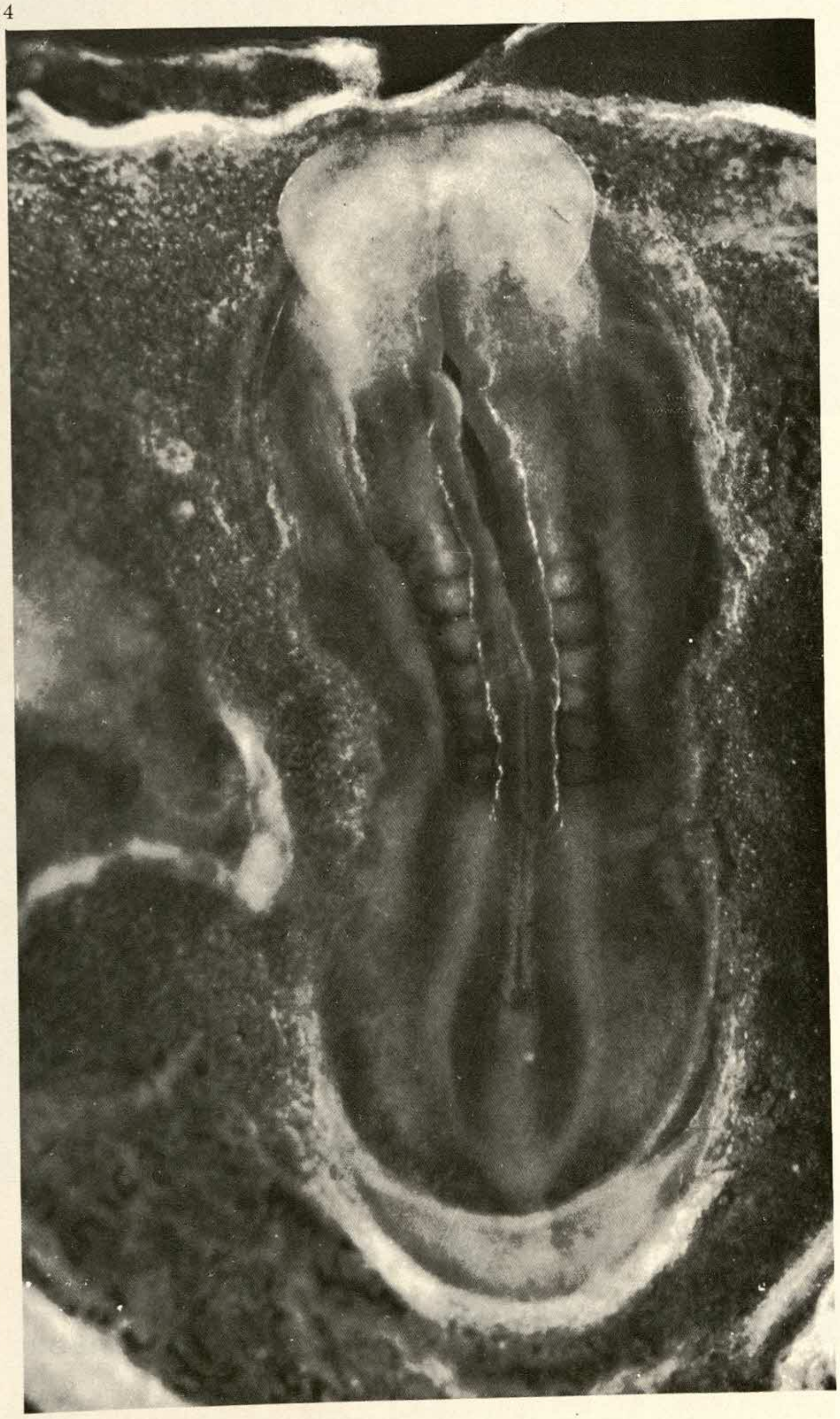
MAMMALIAN EMBRYO AT THE PRIMITIVE STREAK STAGE—Different species of mammals reach this stage at widely different times. The illustration shows a dorsal view of the elliptical embryo. A lighter-colored streak, the primitive streak, is visible in the midline. From the primitive streak, and anterior to the laterally located somites, is the notochord, an early supporting structure that later helps to form the vertebrae. The somites form the skeletal muscles.

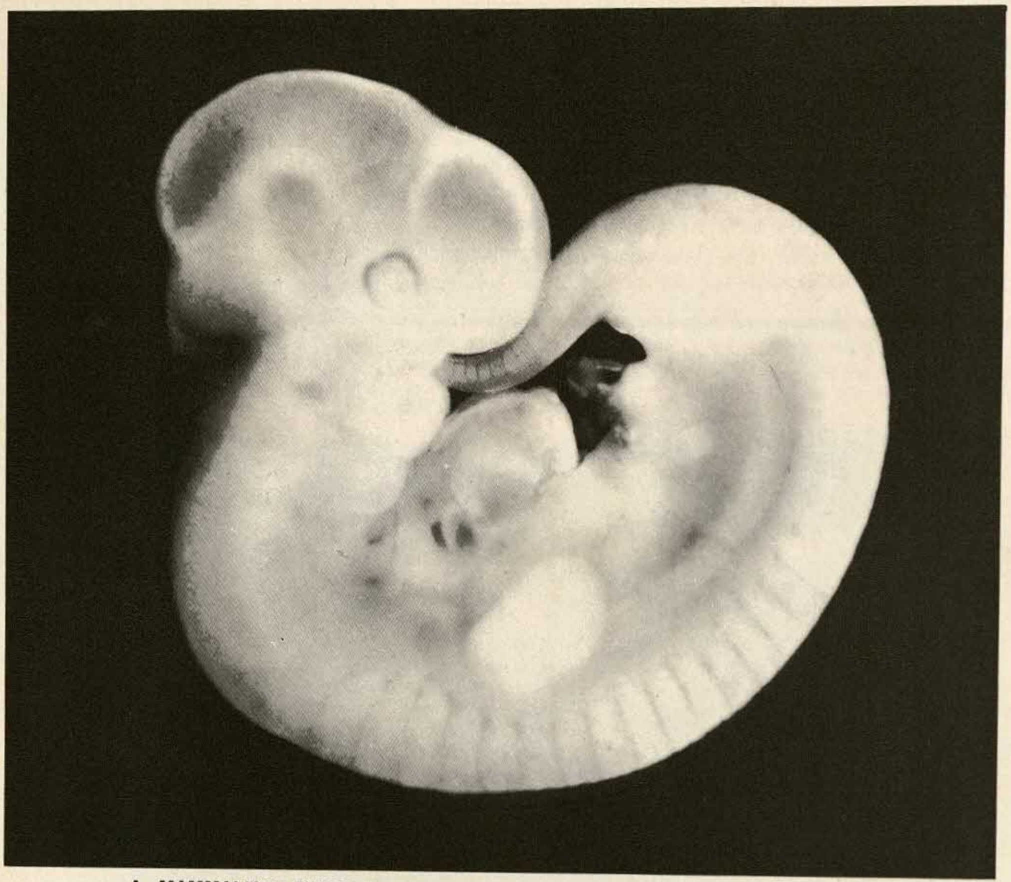
3



A MAMMALIAN EMBRYO IN THE NEURULA STAGE—The neural folds show as fine white lines. The neural groove is open for most of its length. At the extreme anterior end the folds have met, forming the beginnings of the brain. The cut edge of the amnion can be seen just laterad to the embryo. Seven pairs of somites are present.

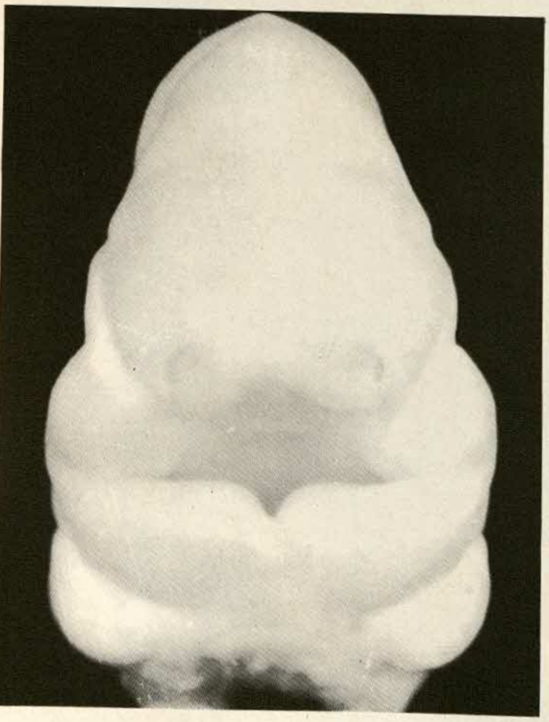
4





A MAMMALIAN EMBRYO WITH WELL-DEVELOPED BRAIN AND HEART—A human embryo would be about four weeks old at this stage. The photograph shows how the embryo curves, with pronounced bends in the neck and tail regions. This side view shows the embryo removed from the uterus with the embryonic membranes cut away. The three main parts of the brain—prosencephalon (forebrain), mesencephalon (midbrain), and rhombencephalon (hindbrain)—show as large bulges in the head region. The dorsal wall of the hindbrain is so thin that it barely shows in the photograph. An eye shows between the fore- and midbrain. Many somites are present along the side of the embryo. The heart projects out from the body just under the forebrain. The light-colored object between the heart and the somites is a front leg.

6

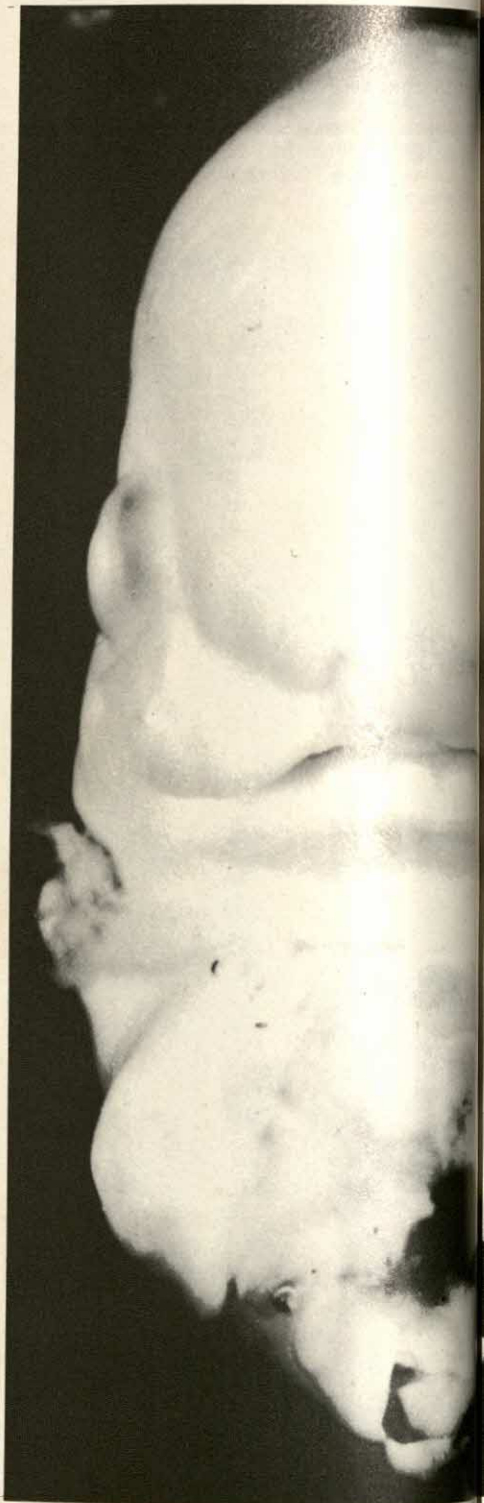


FACE VIEW OF THE HEAD REGION OF A MAMMALIAN EMBRYO—In this photograph, the embryo has been turned so that it is possible to see the developing mouth region. The mandible (lower jaw) below the mouth has a notch in the midline. The olfactory pits that will form the nostrils are visible above the mouth. Below the olfactory pits and to the sides are the maxillary processes that will form the upper jaw.

maternal components of the placenta vary in different species of mammals. The villi of the fetal part are bathed in a liquid from the digested tissues of the uterine wall, tissue fluid, and maternal blood. At no time is there a direct connection between the circulatory systems of the mother and the embryo.

The embryo is encased in the amnion, a sac that develops very early in mammals and in different ways depending on the species. In man it forms from the upper cells of the inner cell mass by a hollowing-out process. It is lined on the inside with ectoderm that is continuous with the ectoderm on the outside of the embryo, and on the outside with mesoderm that is continuous with the mesoderm of the chorion. The amnion fills with a fluid in which the embryo moves freely. This fluid-filled sac protects the embryo from desiccation and from mechanical injuries. As the embryo and amnion enlarge, the amnion fuses with the chorion. Eventually much of the

7a

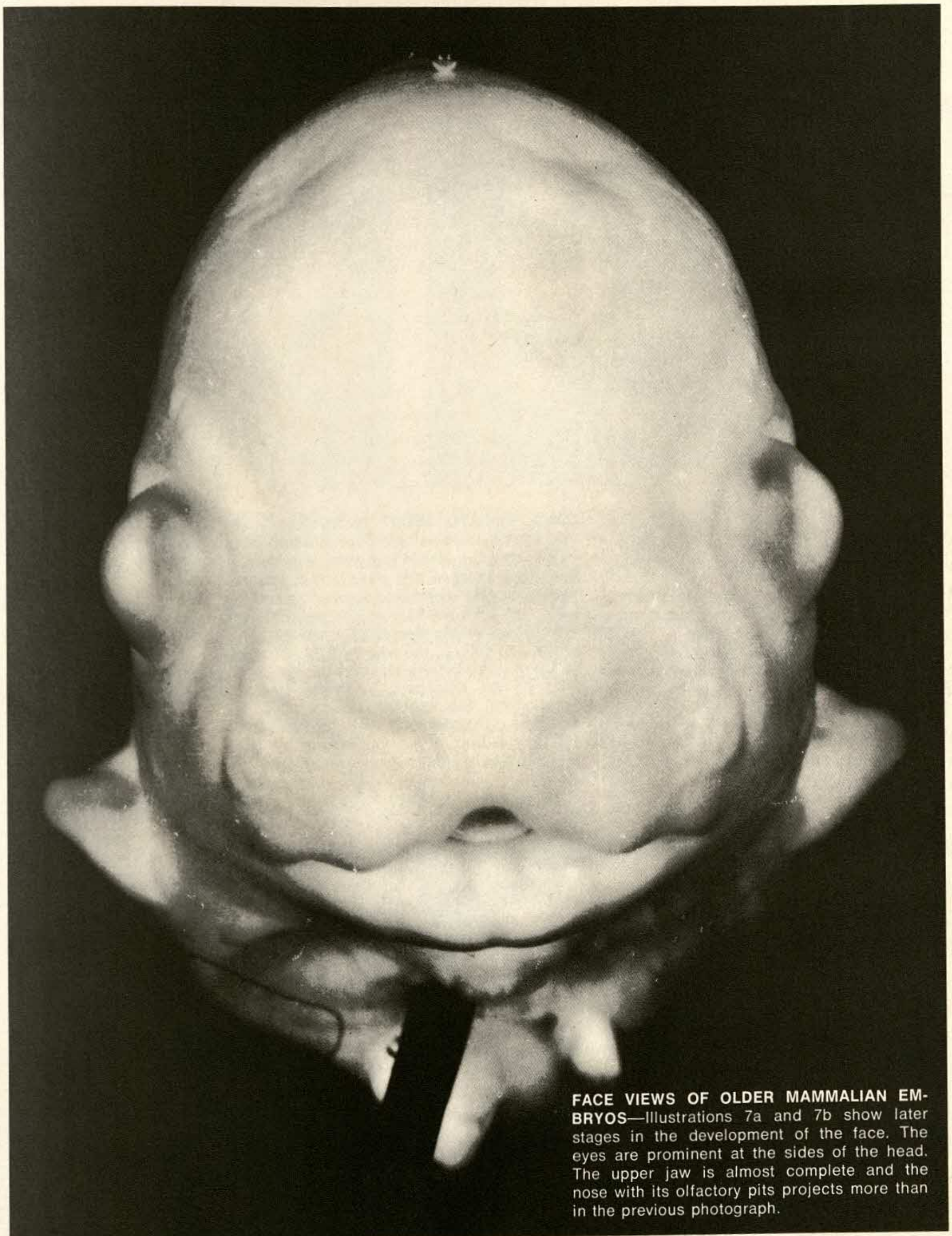


amniotic fluid is absorbed. Marsupial and placental mammals do not have yolk, but they form a vestigial yolk sac by the growth of cells from the ventral side of the digestive tube. The allantois forms as it does in reptiles and birds, from a ventral evagination of the posterior end of the digestive tube.

Both yolk sac and allantois lie within the umbilical cord. The cord, which connects the fetus to the placenta, is covered with part of the amnion and contains, in addition to the vestigial yolk sac and allantois, the umbilical blood vessels. The umbilical arteries carry blood to the chorionic villi of the fetal part of the placenta. In the villi the arteries divide into capillaries and rejoin into a large umbilical vein that brings blood back to the embryo. All exchanges of gases, foods, and waste materials take place through the walls of the villi and capillaries.

Just before birth, the amnion is broken and the amniotic fluid is lost. After birth the placenta is expelled. When the umbilical cord is tied and cut, the newborn baby must breathe by means of its own respiratory system and take in food through its own digestive system, which by then is functioning.

7b

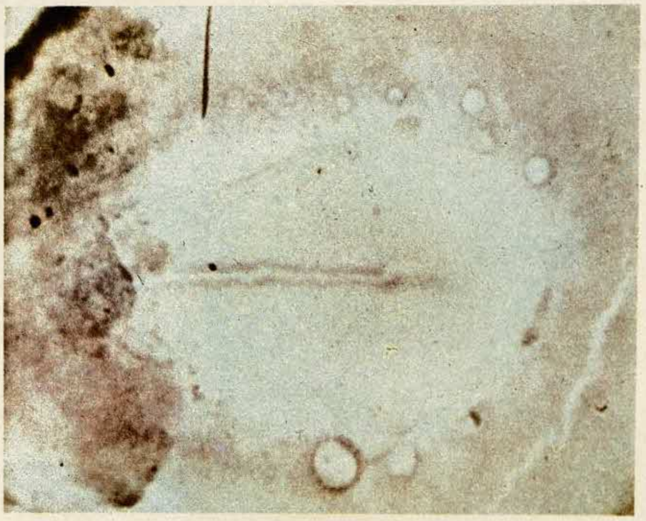


FACE VIEWS OF OLDER MAMMALIAN EMBRYOS—Illustrations 7a and 7b show later stages in the development of the face. The eyes are prominent at the sides of the head. The upper jaw is almost complete and the nose with its olfactory pits projects more than in the previous photograph.

BIRD EMBRYOLOGY

from egg to chick

1



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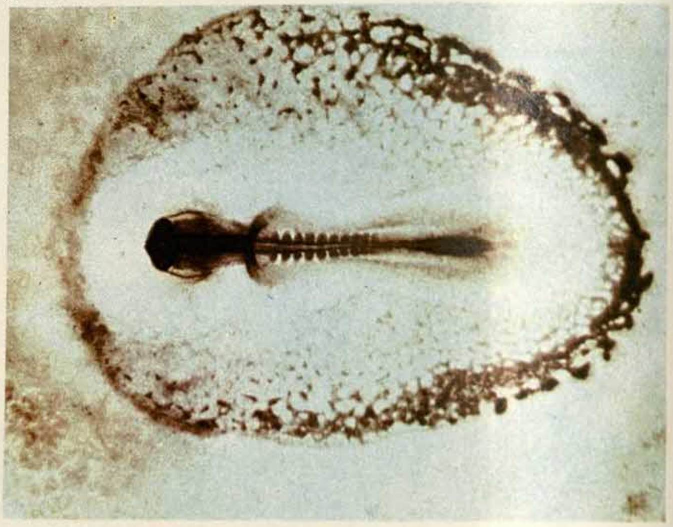


The steps that change a seemingly simple, undifferentiated egg into a complex, self-sustaining animal form one of the most interesting studies in the field of biology. The science of embryology deals with the development of an organism from fertilized egg to independent existence. The end of the embryonic or developmental period is not a precise moment in most animals, but in birds it is usually considered to be the time of hatching and in mammals the time of birth, when the young leaves the body of the mother.

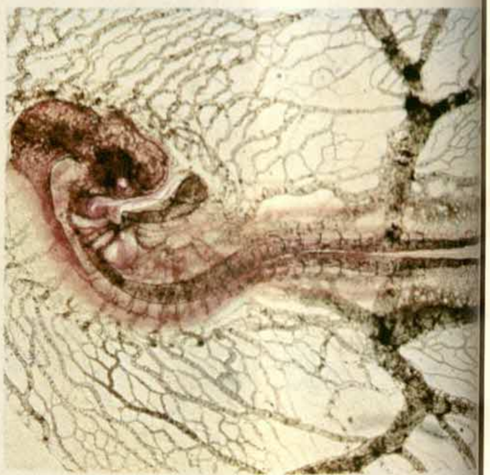
While some stages in development may appear to differ among the various vertebrates, the differences are more superficial than basic and are due chiefly to the way in which the embryo gets its food. Birds, whose embryos must live on yolk and albumen, are well supplied with these foods, while mammalian embryos, whose food is supplied by the mother, have practically no yolk. Since much yolk makes cell division difficult, and since lack of yolk means the necessity for an early food-and-oxygen-conveying system from the mother, some differences in bird and mammalian development appear rather early. The formation of the organ systems, however, is practically the same in all vertebrates.

CHICK EMBRYO ABOUT 20 HOURS OLD— The age of a bird embryo is counted from the time incubation starts. The embryo in Illustration 1 is composed of a clear region, the area pellucida, which lies over a space on top of the yolk, and a peripheral, more dense area—the area opaca—where the cells still adhere to the underlying yolk. In the center of the area pellucida is the primitive streak, with the beginning of the notochord extending from its anterior end. The notochord is a primitive supporting rod that becomes part of the vertebrae of the adult bird. At this time the embryo is in a late gastrula stage, composed of three layers of cells, an upper ectoderm, a lower endoderm, and the mesoderm lying between ectoderm and endoderm.

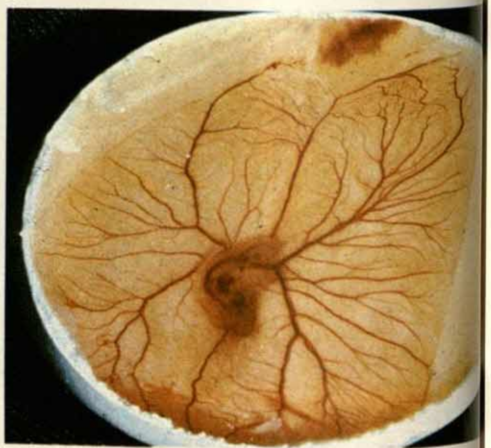
CHICK EMBRYO ABOUT 33 HOURS OLD— The embryo is no longer a flat disk of cells on top of the yolk, but is beginning to take form as some of the organs appear. The brain shows as a conspicuous bulge. The segmentally arranged blocks of tissue are the mesodermal somites that will form the skeletal muscles (Illustration 2).

CHICK EMBRYO ABOUT 72 HOURS OLD— Illustration 3a shows an enlargement of an embryo after the anterior end has twisted so that the left side of the head is lying on the yolk. The brain is large and has become constricted into fore-, mid-, and hindbrain regions. The eye shows as a dark spot in the forebrain region. The heart projects from the body posterior to the brain; large blood vessels connect with the heart. Illustration 3b shows a three- or four-day-old chick lying in the shell, which has been partially removed. The blood vessels extending over the embryonic membranes show very distinctly.

3a



3b



EARLY STAGES IN THE DEVELOPMENT OF A BIRD

Biologically speaking, a bird's egg is what is ordinarily spoken of as the yolk of the egg. The cytoplasm, where cell division takes place, is the small white dot often observed on top of the yolk. The egg (yolk) is held together by the egg (vitelline) membrane. Outside of the egg proper are the albumen, the shell membranes, and the shell, all of which are added after the egg leaves the ovary of the hen.

Fertilization (union of egg and sperm) occurs in the upper end of the oviduct soon after ovulation. Fertilization, as in all animals, initiates the division of the egg. The first few rapid mitotic divisions are spoken of as cleavage or segmentation divisions. The pattern that cleavage takes depends on the amount of yolk present in the eggs of different kinds of animals. Those eggs with little yolk divide completely, forming blastomeres (cells) of equal size; those eggs with more yolk divide completely, forming blastomeres of unequal size. Eggs with large amounts of yolk, as in reptiles and birds, form blastomeres only in the cytoplasmic disk located on top of the yolk. Such eggs, therefore, divide only partially. This partial or discoidal type of cleavage is characteristic of reptiles and birds, whose embryos live on yolk and albumen for several days (21 days in the chicken) before hatching.

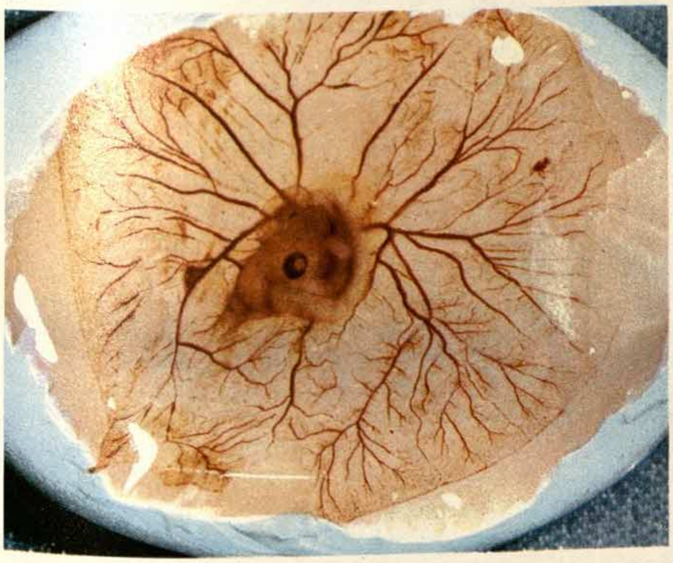
As cleavage continues in the chick, the blastomeres in the center of the disk of cytoplasm become cut off from the underlying and surrounding yolk, while the peripherally forming nuclei do not as yet have definite cell membranes and, therefore, seem to lie in the yolk. By the end of the cleavage period the embryo consists of a mass of blastomeres lying on top of the yolk but separated from it by a small, slitlike cavity. This is the blastula stage of the chick embryo. The central mass of cells appears transparent because of the cavity underneath them. This region is called the area pellucida, while the peripheral, newly forming cells, still attached to the underlying yolk, look more dense and hence constitute the area opaca.

The cleavage divisions take place while the "egg" is traveling down the oviduct of the hen. During this time, albumen, shell membranes, and shell are added around the yolk. The "egg" is laid at about this time. It is made up of an embryo, in the late blastula stage, lying on top of the yolk, plus albumen, membranes, and shell. Eggs that are bought in stores have not been fertilized and do not have embryos. The disk of cytoplasm can, however, be observed.

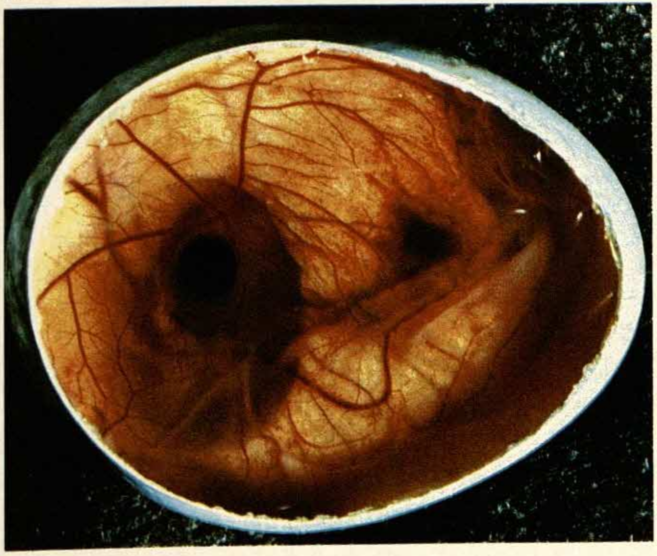
Development continues as soon as the mother bird sits on the eggs or as soon as they are put in an incubator set to maintain a temperature of about 38° C (about 100° F). By continued cell divisions and a somewhat complex migration of cells, the blastula becomes a gastrula composed of a dense, longitudinal strip of cells called the primitive streak. This structure has a slight groove down its

OLDER CHICK EMBRYOS — Illustration 4a shows a chick embryo about five days old. By this time the embryonic membranes are well developed. They are the yolk sac, amnion, serosa, and allantois. All of these develop from the three primary layers of cells that form the embryo but they are not part of the embryo proper. The amnion is a sac surrounding the embryo, and is completely filled with a fluid that protects the embryo from mechanical injuries and allows the embryo to move freely. Contraction of the amnion aids in moving the embryo and in circulating the blood. The yolk sac, which surrounds the yolk, digests the yolk, which is then brought to the embryo by the blood vessels that extend over the surface of the yolk sac. The allantois, which is a saclike outgrowth of the posterior part of the digestive system, grows out between the amnion and serosa; it functions as the embryo's urinary bladder. It is also important, after it fuses with the serosa, in bringing oxygen that has diffused through the shell into the circulatory system. Except for the proximal end (the one closest to the embryo) of the allantois, the embryonic membranes are discarded at the time of hatching. This proximal end becomes the urinary bladder of the adult bird. Illustration 4b shows a chick about seven days old. The darkly pigmented eye is the most conspicuous part of the chick's head. Blood vessels from the fused sero-allantoic membrane bring in oxygen and discharge carbon dioxide by diffusion through the shell.

4a



4b



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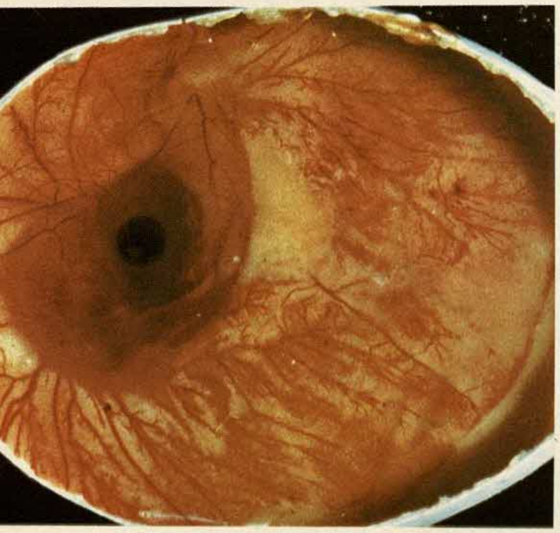
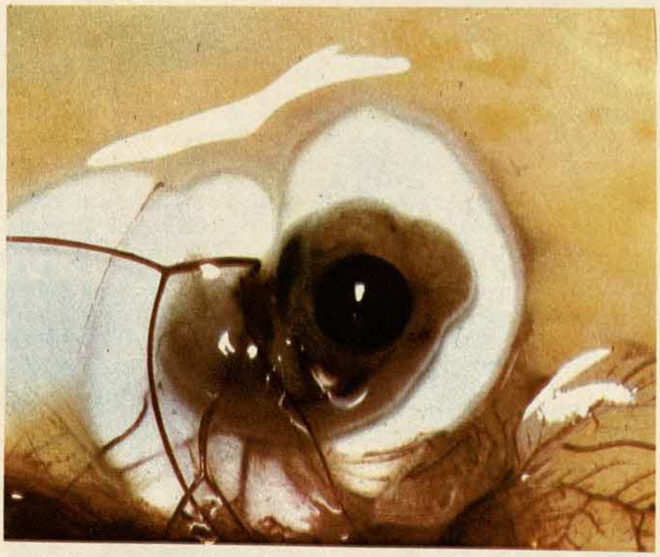


CHICK EMBRYO ABOUT EIGHT DAYS OLD— In Illustration 5 the shell has been cut away to show the embryo lying on top of the yolk. The rich blood supply is conspicuous. The shape of the embryo is obscured by the amnion, but the head with one large eye is clearly visible.

6a



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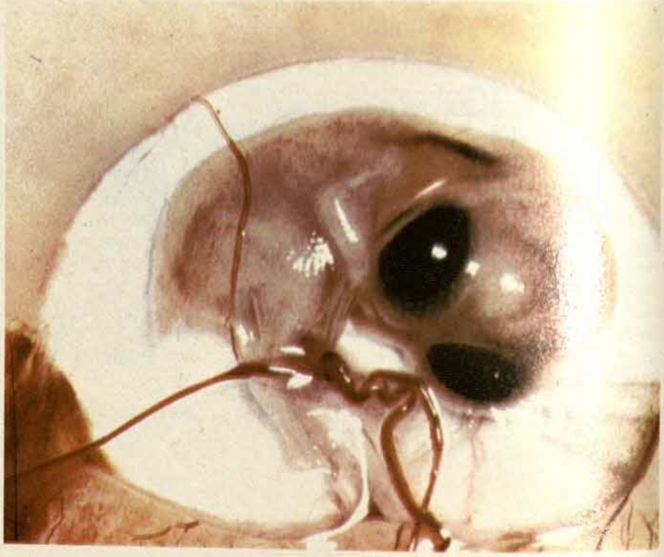


CHICK EMBRYO ABOUT 10 DAYS OLD— Illustration 6a shows the embryo inside the amnion. The head region develops early and is large in proportion to the rest of the body. Illustration 6b shows the limbs; the head is turned so that both of the very large eyes show. Blood vessels bring food to the embryo from the yolk sac. Although the embryo is immersed in fluid, it does not breathe by means of gills. Oxygen is brought to the embryo by the blood vessels after it has diffused through the shell.

center. The embryo is now composed of three layers of cells: an upper ectodermal layer, a lower endodermal layer, and a middle mesodermal layer. Each of these later forms definite organs in a very precise and orderly manner.

ORIGIN OF THE MAJOR ORGAN SYSTEMS

A late gastrula incubated for about 20 hours is considerably larger than the blastula. A dense line of cells growing anteriorly from the primitive streak appears at the end of gastrulation. This is the notochord (sometimes called the head process). The vertebrae will develop from it. All the organ systems are formed from the three embryonic layers (often called the germ layers because they are formative or germinal in nature). The nervous system is derived from the ectoderm and is formed in the following manner: two folds, the neural folds, form at the sides of the notochord, anterior to the primitive streak. These fuse to form the neural tube, which gives rise to the brain and spinal cord. The anterior part of the neural tube grows more rapidly, and as it grows it becomes constricted into five regions. These five basic parts increase in size, then fold to become the brain. The remaining part of the neural tube becomes the spinal cord. The ectoderm also forms the epidermal part of the skin, including the feathers of birds.

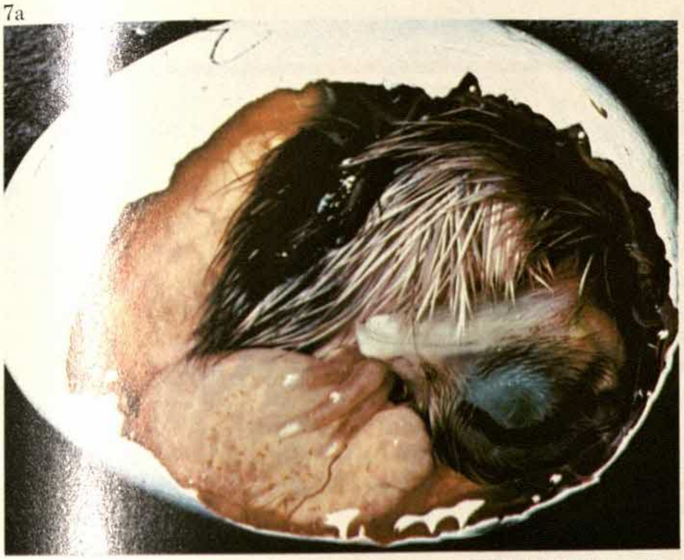
The endoderm forms the lining epithelium of the digestive tube and respiratory system and all of the liver and pancreas.

The mesoderm, in addition to forming the vertebrae, forms all the rest of the skeleton, the muscles, the connective tissues such as tendons and ligaments, the circulatory system including the blood, the reproductive system, and the excretory system.

FORMATION OF EMBRYONIC MEMBRANES

There are four embryonic membranes, often called extraembryonic membranes because they do not form part of the embryo proper, although they are derived from blastomeres of the fertilized egg. They are the amnion, allantois, yolk sac, and serosa (also called the chorion). Fish and amphibia whose embryos develop in water lack embryonic membranes. These are the Anamniota. Reptiles, birds, and mammals who are air-breathing, terrestrial animals whose

7a



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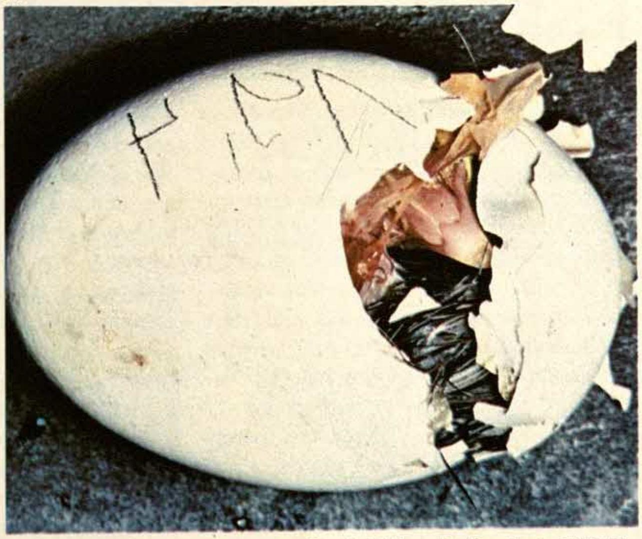


CHICK EMBRYO ABOUT 16 DAYS OLD—Illustration 7a shows the chick almost fully formed; the head with its eyes and beak is folded against the body. Feathers are developing. The allantois is important at this time in respiration and as a storage sac for excretory products. On the nineteenth day the chick begins to breathe with its lungs, perforating the air chamber, located at the larger end of the shell, with its beak and thus receiving oxygen without breaking the shell. The allantois starts to dry up at this time; when the eggshell is broken, most of the allantois adheres to the shell and is discarded. Illustration 7b shows the chick on the twenty-first day as it breaks the shell with a horny egg tooth located on the upper part of the beak. The egg tooth is lost soon after hatching. By the time of hatching the shell has become thinner because part of the calcium carbonate of which it is composed has been utilized by the embryo in the calcification of its bones.

A NEWLY HATCHED CHICK—When the chick first emerges from the shell, its feathers are damp and ruffled but they soon dry and become soft and fluffy. The embryonic membranes have been discarded. For the first day the chick lives on the remains of the yolk, which has been taken inside its body by the shrinking yolk sac. After the first day the chick is ready to eat. In most respects the development and the anatomy of mammals is like that of birds.

embryos do not develop in environmental water have the four embryonic membranes. These animals are the Amniota. In general, the function of the membranes is protection, maintaining a liquid environment for the embryo, bringing food and oxygen to the embryo, and taking carbon dioxide and other metabolic wastes away from the embryo.

In the chick embryo the membranes begin to appear when the embryo is about 36 hours old and are virtually complete when the chick is about five days old. The amnion and serosa develop at the same time from the same layers of cells. Cells lying peripheral to the embryo proper increase rapidly in number and rise up as a continuous fold that soon completely envelops the embryo. The inner part of the fold forms the amnion, a sac around the embryo, soon filled with amniotic fluid in which the embryo floats and moves freely. The outer part of the fold forms the serosa, which eventually covers the yolk sac and allantois as well as the amnion. The serosa lies next to the shell membranes in the later stages of development.

The yolk sac forms from an expansion of the same layers that form the gut. In early stages, yolk lies under the incompleted gut. As the yolk sac grows around the yolk, it gradually separates the yolk from the closing gut. The yolk sac digests the yolk, and blood vessels on its surface bring the digested food to the embryo.

The allantois is a saclike outgrowth of the posterior part of the digestive tube. It becomes large, spreading over the amnion and yolk sac and under the serosa. The allantois functions as an embryonic urinary bladder, accumulating water, urea, and uric acid from the metabolism of proteins. As the allantois becomes larger, part of it fuses with the serosa. This compound membrane develops a rich vascular network that brings oxygen to the embryo and carries carbon dioxide away from the embryo. Since this sero-allantoic membrane is close to the shell, exchange of these gases takes place readily through the shell. The part of the allantois closest to the chick's body eventually forms the urinary bladder of the adult chicken; the remainder of the allantois is discarded at hatching, as are the other embryonic membranes. On its first day, the hatched chick lives on the remains of the yolk.

POLLINATION AND FERTILIZATION | wind, water, and insects

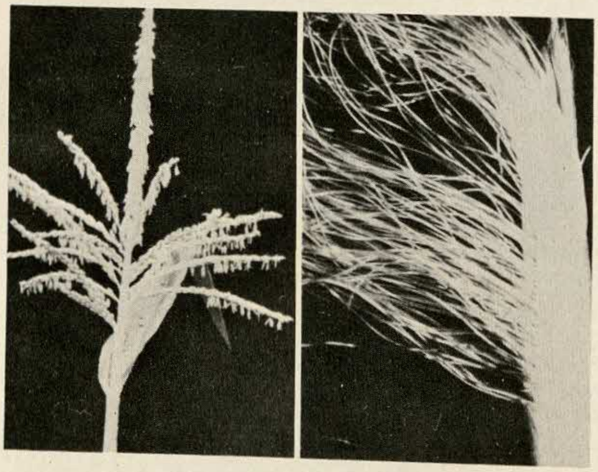
Like animals, most plants reproduce sexually, the female gamete or egg being fertilized by the male gamete or sperm. The sperms of most plants, like those of animals, swim by means of flagella, and fertilization of plants is effected in water or in rainy weather. Important exceptions are the flowering plants and most of the cone-bearing plants, such as pine and hemlock. Their sperms have no flagella and cannot move toward an egg under their own power. Rather, the sperms are formed inside pollen grains, small structures usually consisting of only two, three, or four cells. The pollen grains are produced in the stamens of flowers or in the pollen sacs of cones and are transported—usually by wind or insects—to other flowers or cones. The transport of pollen is called pollination.

Pollination precedes fertilization. In flowering plants, the pollen is effective only if it lands on the stigmas of the pistils. Most stigmas are sticky or have minute papillae that hold the pollen grains and keep them from falling off. The pollen grains germinate after landing on a stigma; they form a long pollen tube that grows down through the stigma and style to the ovary. The ovary contains one or more ovules, each of which contains a single egg.

Usually two sperms are produced; they travel down the pollen tube and are discharged into the ovule, where one of them fertilizes the egg. The fertilized egg develops into an embryo plant; at the same time the ovule ripens into a seed, and the ovary matures into a fruit. Ordinarily only one embryo is present in a seed; but the number of seeds in a fruit depends on the number of ovules originally present in the ovary and on the number of fertilizations that were achieved. If an egg is not fertilized, its ovule usually does not develop into a seed.

The second sperm produced by a pollen grain of a flowering plant is not functionless. Within the ovule are two nuclei called polar nuclei. The second sperm fuses with the polar nuclei, forming a polyploid cell that develops into a tissue called endosperm. In some seeds the endosperm is sparse and does not persist in the mature seed. In others the endosperm becomes an important food-storing tissue on which the embryo depends when it germinates. Much of the nutritive value of cereal grains such as corn, wheat, and rice lies in their large endosperms.

The process of pollination and fertilization in coniferous trees resembles that of flowering plants, but there are some important differences. Cones have no pistils, but the ovules are present on the surface of the cone scales. To be effective, pollen must land on the ovule. If pollination and fertilization occur, the ovule ripens into a seed, but because there is no ovary, no fruit develops. Because the ovule contains no polar nuclei, nothing resembling the endosperm of flowering plants is produced.



1a 1b

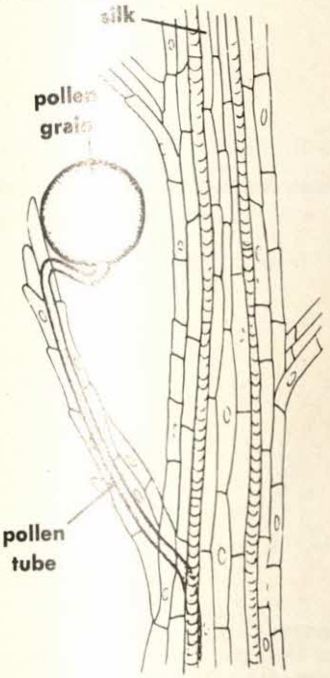
INFLORESCENCES OF CORN — Corn is a monoecious, wind-pollinated plant with staminate flowers in the tassel (Illustration 1a) and pistillate flowers in the ear (Illustration 1b). The anthers dangle freely in the wind, which can catch the copious pollen. Each silk is a long style with many stigmatic surfaces. The ovary of each pistil ripens into a kernel after pollination and fertilization.

AGENTS OF POLLINATION

Because pollen is incapable of moving under its own power, it must be transported by external agents. Wind and insects are the most common agents of pollination, but other small animals transport pollen as well. In a few species of aquatic plants, pollen is carried by water.

Plants that are pollinated by wind produce pollen in great quantities. This is necessary because wind does not often blow pollen directly toward flowers of the same species. Much of the pollen is

2



GERMINATION OF A POLLEN GRAIN OF CORN—After landing on a receptive stigma, the pollen grain forms a long pollen tube that grows through the style to the ovary.

wasted, and only a minute portion of it lands on a receptive stigma. Wind-blown pollen is light and powdery; these characteristics permit it to be transported long distances.

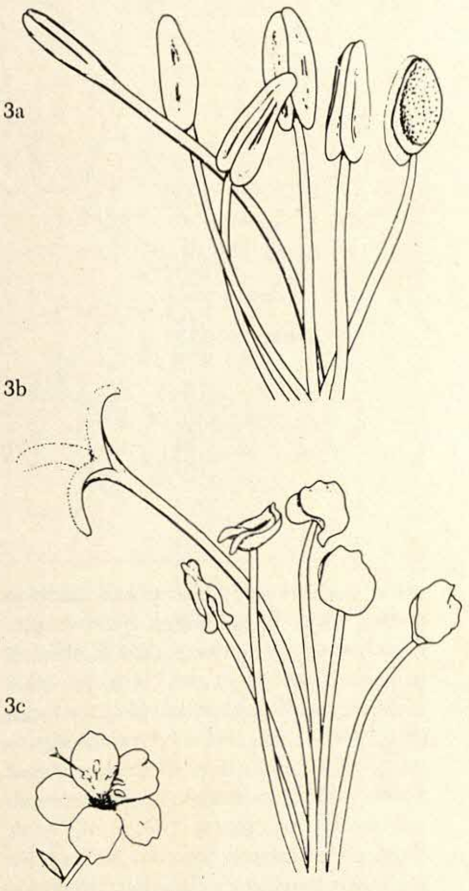
Wind-pollinated plants include many of the conifers and grasses. Among the latter are corn, wheat, and other economically important cereal grains. The petals and sepals of most wind-pollinated flowers are small and inconspicuous or even lacking; thus, they do not interfere with the passage of pollen. The stigmas or styles of wind-pollinated plants often are long or branched, thus increasing the amount of surface area receptive to the pollen. Some of the spring-flowering trees, such as birch, poplar, oak, and walnut have their flowers in slender inflorescences called aments or catkins. The aments are produced before the leaves emerge and are exposed to the wind.

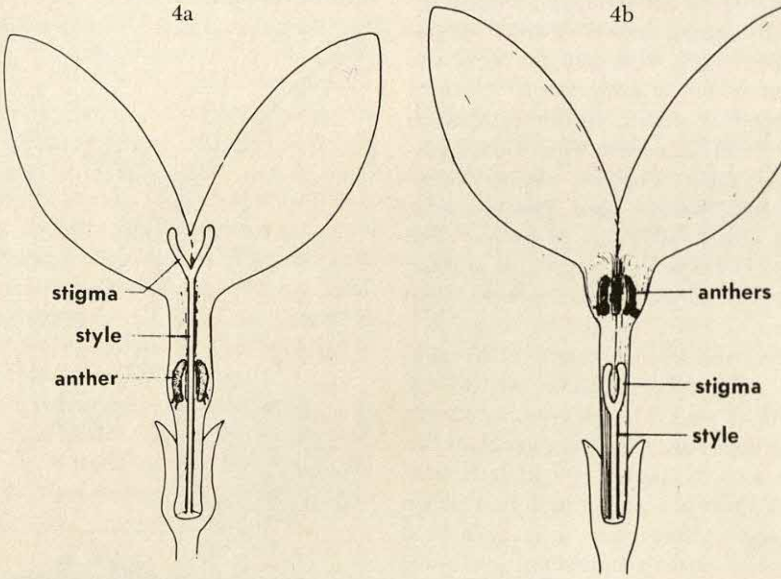
Animal-pollinated flowers have adaptations, many of which are the opposite of those of wind-pollinated flowers. Insects are the most common animal pollinators, and of these, bees, butterflies, and moths probably are the most important. These animals do not move haphazardly among flowers of different species, but usually visit only flowers of one species within a given period of time. Transport of pollen, therefore, is much more direct than when wind is the transporting agent. For this reason insect-pollinated flowers need produce relatively small quantities of pollen. The pollen is sticky, ensuring that at least some of it will adhere to the body of the insect.

Insect-pollinated flowers often produce a sweet nectar that is used by the insects as food. The visits of the insects to the flower are, of course, to obtain this food; and the insects are probably unaware that they are transporting pollen at the same time. Some insect-pollinated flowers, such as snapdragons and some mints, have petals fused into a tube open at only one end; as the insect moves about in the tight quarters within the flower, it can hardly avoid depositing some pollen that it received from a previously visited flower and receiving fresh pollen from the present flower. Many flowers have bright, colorful petals that attract insects; among them are the orchids, composites, milkweeds, snapdragons, and mints. Poinsettia has brilliant bracts that perform the same function.

Odors of various sorts are emitted by many flowers when they are ready for

DICHOGAMY—The stamens in the flowers of Jacob's ladder (*Polemonium caeruleum*) mature before the stigmas are receptive (Illustration 3a). When the anthers shed their pollen, the three lobes of the stigma are folded together. After the pollen is shed, the stigma lobes spread apart (Illustration 3b) and are receptive to pollen from other flowers. Illustration 3c shows the complete flower.





HETEROSTYLY—Some cornflowers (*Houstonia caerulia*) have short stamens and long styles (Illustration 4a), while others have long stamens and short styles (Illustration 4b). Insects transfer pollen from short stamens to short-styled pistils and from long stamens to long-styled pistils.

insect pollination. Some plants, such as clover, which is pollinated by bees, produce a fragrant perfume that is pleasant to human beings as well. On the other hand, such fly-pollinated plants as carrion flower attract flies by producing an odor resembling that of rotting meat. Some orchids resemble certain female insects in size, shape, color, and odor; they are pollinated by male insects that approach them in an apparent attempt to mate with them. Most bee- and butterfly-pollinated flowers are open by day when these insects are active. Moth-pollinated flowers tend to open at night, when most moths are active.

CROSS-POLLINATION

It is a general rule in the biological world that inbreeding is less desirable genetically than outbreeding. Outbreeding produces a larger variety of genetic types, and ordinarily produces sturdier offspring. Most species have adaptations that make self-fertilization impossible or unlikely. Some exceptions are tomatoes, peas, tobacco, and cotton, which are self-pollinated regularly.

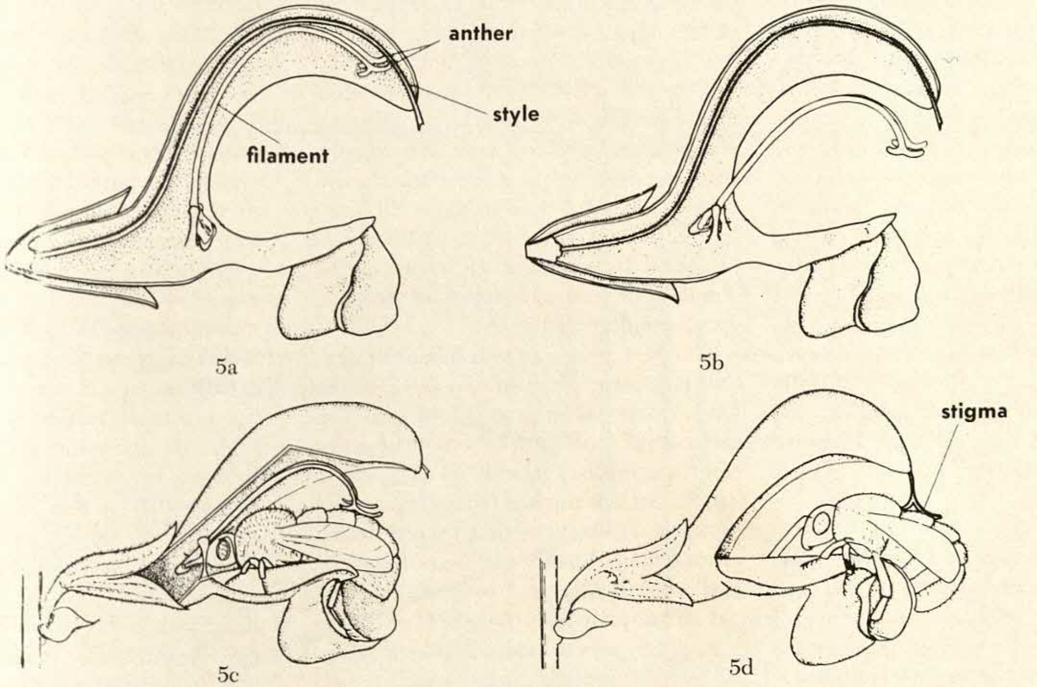
Self-pollination is impossible in those plants that have staminate flowers (flowers with stamens but no pistils) and pistillate flowers (those with pistils but no stamens) on separate plants. Such plants are dioecious; willows, date palms, and hemp are examples. Monoecious plants have staminate and pistillate flowers on the same plant; self-pollination is possible but less likely than cross-pollination. Monoecious plants include oaks, walnuts, and corn.

Some plants with perfect flowers (those with both pistils and stamens) are self-incompatible, the pollen failing to germinate if it lands on a pistil of the same plant. Many fruit trees are self-incompatible; to ensure fruit, a farmer plants trees of at least two varieties of the same species in his orchard.

Dichogamy is the maturation of stamens and pistils of the same flower at different times. Flowers of Jacob's ladder and red clover release their pollen before the stigmas are receptive, and an avocado flower sheds its pollen when the stigma is no longer receptive. Because different flowers of the species are in different stages at any one time, cross-pollination is likely.

Heterostyly is an adaptation exhibited by cornflowers, primroses, buckwheat, and loosestrife. In some flowers, the stamens are short and the styles are long;

INSECT POLLINATION IN SAGE—The flowers of sage (*Salvia pratensis*) are dichogamous. The stamens mature before the stigmas are receptive (Illustration 5a). The bases of the two stamens are fused. If the fused bases are pushed backward, the anthers are tilted downward and forward (Illustration 5b). When a bee enters a young flower in search of nectar, its head strikes the bases of the stamens, and pollen from the anthers is deposited on its back (Illustration 5c). In older flowers the style bends downward and forward. If a bee enters the flower, the stigmas are brushed by the bee's back (Illustration 5d). If the bee carries pollen from a visit to another sage flower, pollination is achieved. When the stamens ripen before the stigmas, dichogamy is known as protandry.



5a 5b 5c 5d

in other flowers of the same species, the stamens are long and the styles are short. When an insect enters a flower with short stamens, the pollen is deposited on its body in such a position that it will be brushed onto the stigma of only a short-styled flower that it might visit later. On the other hand, if the insect visits a flower with long stamens, the pollen it receives will be transferred only to the stigma of a long-styled flower.

CONTROLLED POLLINATION WITH HONEYBEES

Although the honeybee is not the most efficient pollinator for some plants, it is the only insect that can be controlled so that desired numbers can be obtained where and when needed. Of course, the plants that require insect pollination always did require it; and it occurred naturally until the practices of modern agriculture produced extensive areas of pure stands of crops that produce pollen and nectar for a relatively short portion of the year. Because insect pollinators, especially honeybees, need a steady supply of food throughout their active period, they have been forced to disperse to more promising wild fields, and many pollinators have been greatly reduced in number. The extensive use of herbicidal chemicals to eliminate weeds and to control insect pests (which are pollinators as well) has intensified the problem.

The number of bees needed for efficient pollination varies with the crop. One colony per acre is usually recommended for fruit trees; two to four colonies may be needed for abundant blooms, such as clover or alfalfa; and melons may need only one colony to several acres. If the crop is not a major honey plant but requires pollination at the time the honey crop usually is produced, the beekeeper must be paid enough for the services of the bees to cover not only the cost of moving but also the value of the honey. Nor does the presence of the bees assure the pollination of a particular crop; another plant blooming within the flight area may attract the bees. In some areas, food plants are lacking in certain seasons; thus, bees must be introduced when the blooming begins and removed as soon as pollination is over. Despite such limitations, farmers and beekeepers, with the aid of entomologists, have developed a rather successful use of honeybees in the pollination of major crops. The value of bees as pollinators exceeds the value of their honey and wax production.

DIGESTION AND ABSORPTION

functions of the digestive system

A balanced meal is rich in nutrients. Meats and milk provide proteins and fats. Potatoes, rice, and bread contain starch, and many fruits are sources of sugar. Vegetables vary a great deal in their nutrient content. In their natural state most foods contain a significant quantity of some vitamins and minerals. All of these substances are of potential value to the human body, but after they are eaten, they must be absorbed from the lumen of the digestive tract into the cells of the body before they can be utilized. Many of the food molecules are insoluble macromolecules that cannot be absorbed by the body, and they must be digested to their smaller soluble components, which can be absorbed. It is the function of the digestive system to digest starch and disaccharides to monosaccharides, fats to glycerol and fatty acids, and proteins to amino acids; and then to absorb the products of digestion.

DIGESTION

The macromolecules in foods are quite stable and are not likely to be digested to simple compounds in the absence of enzymes. Once they enter the human digestive system, however, foods are exposed to an array of digestive enzymes. In order to function, enzymes must make physical contact with their substrates. Because enzymes themselves are macromolecules, they cannot penetrate readily into solid masses of food and can act only on the substrate molecules at the surface of any piece of food. The mechanical breaking up of food into smaller pieces speeds digestion by exposing more surface area on which enzymes can act.

The digestive process can be divided into mechanical digestion and chemical digestion. The former includes chewing, manipulation of food with the tongue, churning movements of the stomach, and segmental contractions in the small intestine. Chemical digestion, or hydrolysis, is catalyzed by enzymes. In many of the digestive organs, both types of digestion occur simultaneously.

The first phase of mechanical digestion is accomplished by the teeth as the food is chewed into small pieces. The presence of food causes the flow of saliva from the salivary glands in the mouth. Saliva contains amylase (sometimes called ptyalin), an enzyme that digests starch to maltose. Salivary amylase functions best in a slightly acid solution, and the pH of saliva usually ranges from 6.5 to 6.8, slightly on the acid side of neutral. In addition to amylase, saliva contains mucus, a slippery substance that lubricates the food and eases passage along the digestive tract.

Starch is a polysaccharide formed by condensation reactions between glucose molecules; the digestion of starch is not exactly the reverse of this, for amylase does not remove glucose units from the starch molecule. Rather it removes disaccharide units that are maltose molecules. These are further acted on by the enzyme maltase in the small intestine.

The chewing action of the teeth and the manipulation of the food by the tongue assist in the mixing of the amylase with the particles of food. Because food remains such a short time in the mouth, relatively little of the starch present in food is digested there. If a starch food like bread is held purposely in the mouth for a long time, the taste of sugar may be perceived as maltose accumulates.

Food that is swallowed is conveyed quickly to the stomach through the esophagus by peristaltic action of the muscular wall of the esophagus. When food enters the upper part of the esophagus, a ring of muscles located just above the food contracts. At the same time, the muscles below the food are relaxed. A wave of muscular contraction moves down the esophagus, forcing the food to move downward ahead of it. During the short period of time that the food is in the esophagus, the amylase continues to function; but when the food enters the stomach, the acid conditions there inactivate the enzyme.

Pepsin is the protein-digesting enzyme secreted by glands in the mucosa that lines the stomach wall. Although proteins are synthesized by the addition of single amino acids to a growing polypeptide chain, they are not necessarily digested that way. Pepsin attacks only certain places in a protein molecule; it splits peptide bonds next to only two amino acids, phenylalanine and tyrosine. The products of this digestion are polypeptide chains, their numbers and their lengths depending on the size of the original protein molecules and the location of phenylalanine and tyrosine within the molecule. The polypeptides are digested further by other enzymes in the small intestine.

Pepsin functions best in a highly acid pH, and this is provided by the hydrochloric acid that is secreted by the di-

THE CHEMISTRY OF DIGESTION—Many of the food elements that man ingests are insoluble and must be digested to simpler, soluble compounds before they can be absorbed into the circulatory system. Enzymes produced by the digestive system catalyze these reactions.

CHEMICAL DIGESTION OF SOME COMMON FOODS

$$\text{starch} + \text{water} \xrightarrow{\text{amylase}} \text{maltose}$$

$$\text{maltose} + \text{water} \xrightarrow{\text{maltase}} \text{glucose}$$

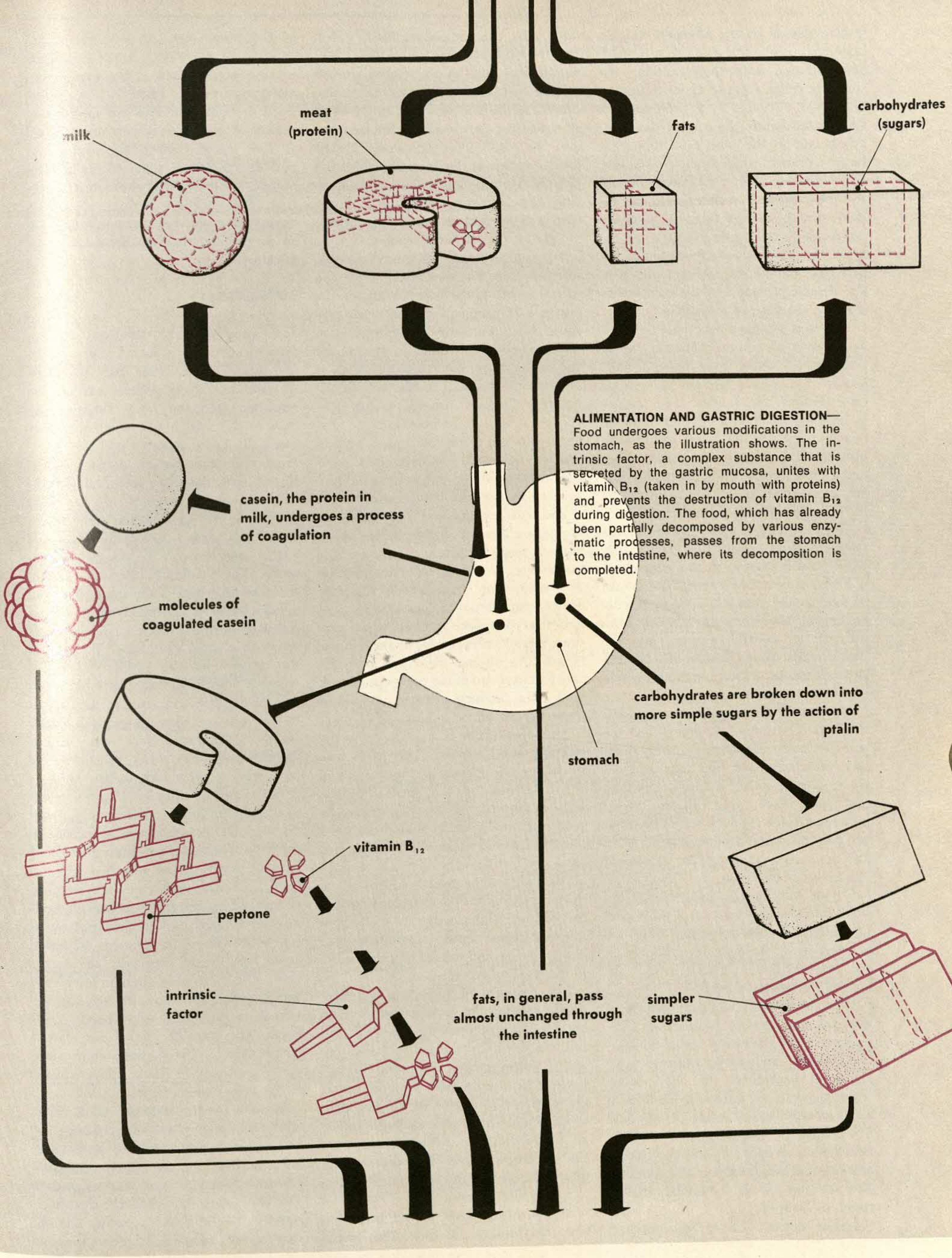
$$\text{sucrose} + \text{water} \xrightarrow{\text{sucrase}} \text{glucose} + \text{fructose}$$

$$\text{lactose} + \text{water} \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$

$$\text{proteins} + \text{water} \xrightarrow[\text{chymotrypsin}]{\text{pepsin, trypsin,}} \text{polypeptides}$$

$$\text{polypeptides} + \text{water} \xrightarrow[\text{aminopeptidase}]{\text{carboxypeptidase,}} \text{amino acids}$$

$$\text{fats} + \text{water} \xrightarrow{\text{lipase}} \text{fatty acids} + \text{glycerol}$$



ALIMENTATION AND GASTRIC DIGESTION—Food undergoes various modifications in the stomach, as the illustration shows. The intrinsic factor, a complex substance that is secreted by the gastric mucosa, unites with vitamin B_{12} (taken in by mouth with proteins) and prevents the destruction of vitamin B_{12} during digestion. The food, which has already been partially decomposed by various enzymatic processes, passes from the stomach to the intestine, where its decomposition is completed.

milk
meat
(protein)
fats
carbohydrates
(sugars)
casein, the protein in milk, undergoes a process of coagulation
molecules of coagulated casein
stomach
carbohydrates are broken down into more simple sugars by the action of ptalin
vitamin B_{12}
peptone
intrinsic factor
fats, in general, pass almost unchanged through the intestine
simpler sugars

gestive glands of the stomach. Gastric juice has a pH of 1 when it is formed; after dilution with food reaching the stomach, it has a pH of about 3. Pepsin, like other enzymes, is a protein. It is synthesized within the cells of the stomach glands in the form of a somewhat larger protein molecule, pepsinogen, which has no enzymatic activity. When the pepsinogen is secreted into the lumen of the stomach, contact with the hydrochloric acid removes part of the molecule. The remaining portion is the active enzyme pepsin. Contact with pepsin already present in the stomach also converts pepsinogen to pepsin.

Rennin is an enzyme secreted by stomach glands of young mammals, whose main protein source is the casein of milk. Casein is a soluble protein that would pass through the stomach too quickly to be digested if it were not for rennin, which coagulates the casein to an insoluble curd. In this form, casein moves much more slowly through the stomach and is exposed to the action of pepsin for a longer period of time.

The secretion of gastric juice by the stomach glands ordinarily occurs only when food is present in the stomach or is likely to be present soon. The arrival of food in the stomach initiates the secretion of the hormone gastrin, from cells of the stomach mucosa, into the bloodstream. When gastrin reaches the stomach glands, it causes them to secrete gastric juice into the stomach.

Mechanical digestion continues in the stomach. Peristaltic movements of the strongly muscular stomach wall churn the stomach contents, thus breaking solid pieces of food into still smaller particles and mixing them well with the several secretions of the stomach wall. The stomach contents, or chyme, become liquefied and are forced by peristaltic movement into the small intestine.

Chyme entering the duodenum of the small intestine still contains a great deal of undigested material, much of which is acted on by the enzymes produced in the pancreas and in glands in the mucosa of the intestinal wall.

Pancreatic juice contains a mixture of enzymes and sodium bicarbonate. The enzymes function best in a slightly alkaline solution. Sodium bicarbonate is alkaline; it neutralizes the acid chyme when the latter reaches the duodenum and makes it alkaline with a pH of about 8.5. Pancreatic juice contains amylase, lipase, and several enzymes that digest proteins and polypeptides. The amylase, like the amylase of the saliva, digests starch to maltose.

Lipase digests fats to glycerol and fatty acids. Fats are not soluble in water, and they tend to unite into large globules that present only a relatively small surface area to the enzymes. Bile salts, present in the bile produced in the liver, stored in the gall bladder, and secreted into the small intestine, emulsify fats. Emulsification is the breaking up of the large fat globules into small, stable droplets. This increases the amount of surface area exposed to lipase, thus hastening the process of fat digestion.

Trypsinogen and chymotrypsinogen, secreted into the duodenum from the pancreas, are inactive precursors of the enzymes trypsin and chymotrypsin, respectively. After it enters the duodenum, trypsinogen is converted to trypsin by another enzyme, enterokinase, which is secreted by the cells in the wall of the intestine. Trypsin also effects this conversion as well as the conversion of chymotrypsinogen to chymotrypsin. Trypsin and chymotrypsin catalyze the digestion of proteins to polypeptides. Trypsin breaks peptide bonds next to the amino acids arginine and lysine; and chymotrypsin breaks bonds adjacent to phenylalanine, tyrosine, tryptophan, methionine, and leucine. The products of trypsin and chymotrypsin digestion are polypeptides of various kinds.

Carboxypeptidase secreted by the pancreas digests polypeptides by the removal of amino acids one at a time from the free carboxyl end of the polypeptide molecule. The products of carboxypeptidase digestion are amino acids.

Aminopeptidase is another polypeptide-digesting enzyme, but it is produced by the glands in the mucosa of the duodenum of the small intestine. Like carboxypeptidase, it functions by removing single amino acids from polypeptide molecules, but it acts at the free amino end of the molecule. The mucosa of the duodenum produces several enzymes that digest disaccharides to monosaccharides. Maltase digests maltose to glucose; lactase digests lactose to glucose and galactose; and sucrase digests sucrose to glucose and fructose.

The entrance of food into the duodenum causes the production of three hormones, cholecystokinin, secretin, and pancreozymin, by the cells of the mucosa. Cholecystokinin stimulates the gall bladder to secrete bile; secretin causes the pancreas to secrete its alkaline pancreatic juice; and pancreozymin causes an increase in the enzyme content of the pancreatic juice. The gastrin produced by the stomach also stimulates secretion of pancreatic juice.

As in other parts of the digestive system, mechanical digestion also occurs in the duodenum. At any given moment, rings of smooth muscle contract, causing constrictions every few inches along this organ. Food is forced forward or backward into the intervening regions where the muscles are relaxed. A few minutes later, the contracted muscles relax, and some of the relaxed muscles contract. This alternate contraction and relaxation of rings of muscles mixes the food with enzymes. Peristalsis keeps food moving along the small intestine.

ABSORPTION

The products of digestion include monosaccharides, glycerol, fatty acids, and amino acids. These are all soluble in water to varying degrees and can be absorbed into the body through the cells of the wall of the small intestine, especially in the jejunum and the ileum. Here the inner surface of the wall is thrown into fingerlike folds called villi. The absorbing surfaces of the cells lining the villi have similar but smaller projections called microvilli; they are visible only through the electron microscope. These foldings increase greatly the absorbing area of the small intestine.

Each villus is equipped with a blood capillary network that connects a small artery to a small vein. Blood flows from the artery into the capillary network where it absorbs the water-soluble products of digestion. From here they move to the vein and then are carried by the blood to the liver. Here some of the molecules may be stored, or they may be carried to other parts of the body.

Fat digestion usually is not carried to completion in the duodenum, and undigested fat molecules are absorbed by the villi. These do not enter the blood directly, but they are absorbed into the lacteals, minute vessels of the lymphatic system, which transports lymph. Lymph resembles blood, but it lacks red blood cells and some of the proteins of blood. Some fatty acids, especially the larger ones, which are only slightly soluble in water, enter the body by way of the lacteals rather than the blood capillaries. The lacteals empty into larger lymph vessels. These finally empty into the bloodstream in the subclavian veins in the upper part of the thorax.

In addition to digested food, vitamins and minerals are absorbed by the villi. Because most of the substances are absorbed against a concentration gradient, energy must be expended. This energy is released by the metabolic activities of the absorbing cells. The absorption of some substances presents

SUBSTANCES SECRETED BY THE DIGESTIVE SYSTEM

SUBSTANCE	SOURCE	SITE OF ACTION	FUNCTION
amylase	salivary glands	mouth	digestion of starch to maltose
pepsin	stomach glands (secreted as pepsinogen)	stomach	1. conversion of pepsinogen to pepsin 2. digestion of proteins to polypeptides
hydrochloric acid	stomach glands	stomach	1. conversion of pepsinogen to pepsin 2. acidifying stomach contents to optimum pH for pepsin
rennin	stomach glands (young mammals only)	stomach	coagulation of the casein in milk
gastrin	stomach mucosa	stomach glands and pancreas	stimulates stomach glands to secrete gastric juice and pancreas to secrete pancreatic juice
bile salts	manufactured in liver and stored in gall bladder	small intestine	emulsification of fats
lipase	pancreas	small intestine	digestion of fats to glycerol and fatty acids
amylase	pancreas	small intestine	digestion of starch to maltose
sodium bicarbonate	pancreas	small intestine	neutralization of acid chyme entering the small intestine and rendering it alkaline
trypsin	pancreas (secreted as trypsinogen)	small intestine	1. digestion of proteins to polypeptides 2. conversion of trypsinogen to trypsin 3. conversion of chymotrypsinogen to chymotrypsin
chymotrypsin	pancreas (secreted as chymotrypsinogen)	small intestine	digestion of proteins to polypeptides
carboxypeptidase	pancreas	small intestine	digestion of polypeptides to amino acids
enterokinase	small intestine	small intestine	conversion of trypsinogen to trypsin
aminopeptidase	small intestine	small intestine	digestion of polypeptides to amino acids
maltase	small intestine	small intestine	digestion of maltose to glucose
lactase	small intestine	small intestine	digestion of lactose to glucose and galactose
sucrase	small intestine	small intestine	digestion of sucrose to glucose and fructose
cholecystokinin	small intestine	gall bladder	stimulation of gall bladder to secrete bile
secretin	small intestine	pancreas	stimulation of pancreas to produce pancreatic juice
pancreozymin	small intestine	pancreas	stimulation of pancreas to produce pancreatic enzymes
mucus	many glands throughout digestive system	digestive tract	lubrication of food

peculiar problems. Most calcium salts are relatively insoluble and, therefore, would not be likely to be absorbed, but the presence of vitamin D and lactose greatly increases the ability of the body to absorb calcium. The linings of both the stomach and intestine secrete a substance called intrinsic factor. It is essential for the absorption of cyanocobalamin (vitamin B_{12}), the antipernicious anemia factor. Persons who, because of some abnormality, do not secrete intrinsic factor suffer from anemia.

Some water is absorbed in the small intestine, but most of the water ingested with food is absorbed through the walls of the large intestine. The remaining material consists largely of indigestible material and is eliminated through the rectum and anus as compacted fecal material.

THE PHYSIOLOGY OF THE KIDNEY | the excretion of toxic substances

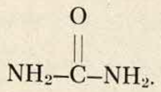
To be alive is to metabolize foods, and to metabolize foods is to produce wastes. All living things have one or more structures devoted to the elimination of wastes. The human body has several: for example, the lungs that eliminate carbon dioxide with every exhalation; the sweat glands of the skin that excrete a liquid similar in composition to urine. But the principal organs of excretion in the human body are its two kidneys, through which about 75 percent of the body's wastes are eliminated.

AMMONOTELIC, UREOTELIC, AND URICOTELIC ANIMALS

In their food, animals take in protein that is rich in nitrogen. During the metabolism of protein, the nitrogen is released in ammonia (NH_3), a highly soluble gas that is extremely toxic to cells. It is essential that this compound either be removed from the organism or be converted to a less toxic waste product. On the basis of the type of nitrogenous compounds excreted, animals can be classified into three groups: ammonotelic animals excrete ammonia; ureotelic animals excrete urea; and uricotelic animals excrete uric acid.

Nearly all aquatic animals are ammonotelic, for when the ammonia is excreted into the environment it is quickly diluted as it spreads throughout the water which is present in abundance.

Most mammals, including man, are ureotelic. In their livers, they convert two of the waste products of their metabolism—carbon dioxide and ammonia—into urea:



$$NH_2-\overset{\overset{O}{||}}{C}-NH_2.$$

Soluble in water, urea, which is transported from the liver to the kidneys by the circulatory system, is not quite so toxic as ammonia. The function of the kidneys is to remove urea from the blood and to concentrate it in the urine.

One group of ureotelic aquatic animals consists of the cartilaginous marine fishes, which animals live in salty water. If there were no adaptation to living in such an environment, the water in the bodies of these fishes would be drawn out of their bodies by the process of osmosis. Instead, they produce urea, which circulates in their bloodstreams at a concentration of more than 2 percent. Because of this, the osmotic pressure of their blood is a little higher than that of the seawater, and water does not diffuse out of their bodies.

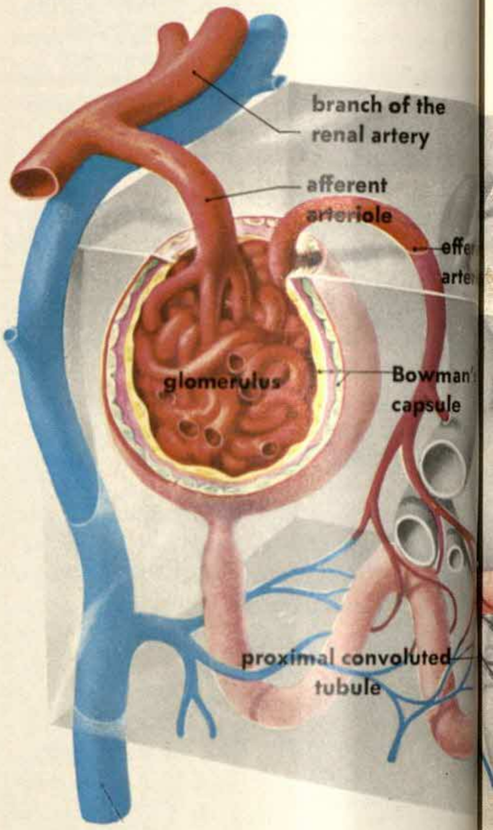
Uricotelic animals include those terrestrial animals that live in dry areas where the water supply is limited. Lizards and snakes of the deserts, for instance, must conserve water and cannot excrete a great deal of it in their urine. These animals convert ammonia to uric acid, an insoluble compound that is not toxic. It can be excreted in a relatively concentrated form. Birds and insects also excrete uric acid. Many uricotelic animals lay eggs with hard shells that must survive with only the quantity of water present in the egg when it was laid. In such a case the conversion of the metabolic wastes of the embryos to uric acid is especially valuable because it can be stored within the egg without poisoning the embryos before they hatch.

Some organisms change their excretion products as they mature. The frog, which is an amphibian, is ammonotelic as a tadpole, but ureotelic as an adult.

THE FUNCTION OF THE HUMAN KIDNEY

The kidney consists of about a million nephrons, which are its functional units. The nephrons are served by blood vessels that bring to them blood containing urea and other waste products of metabolism and that carry away blood from which the wastes have been removed. The total volume of the body's blood passes through the kidneys once in about 25 minutes.

Each nephron consists of four parts: Bowman's capsule, the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule. The renal arteries conduct blood from the aorta to

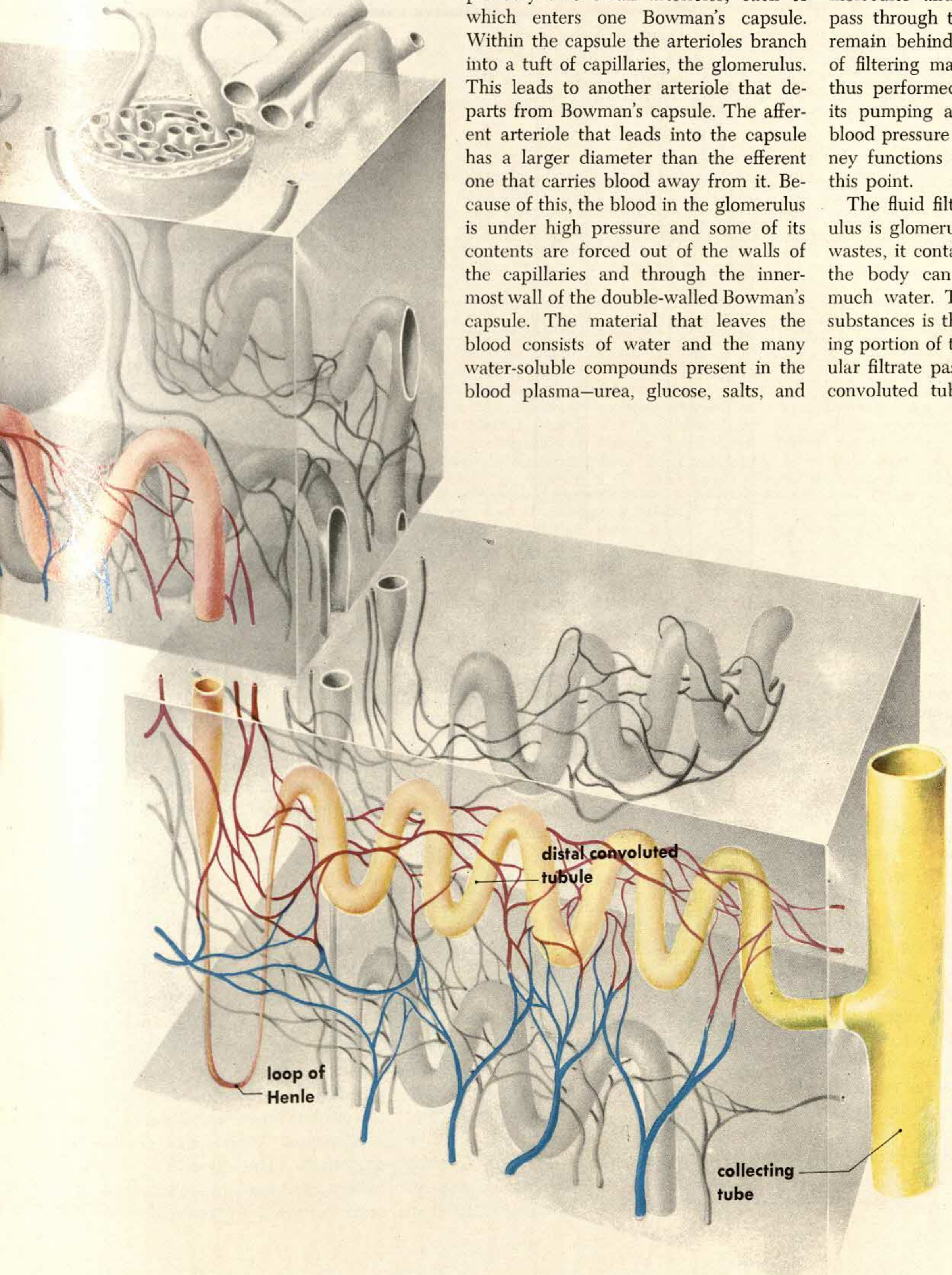


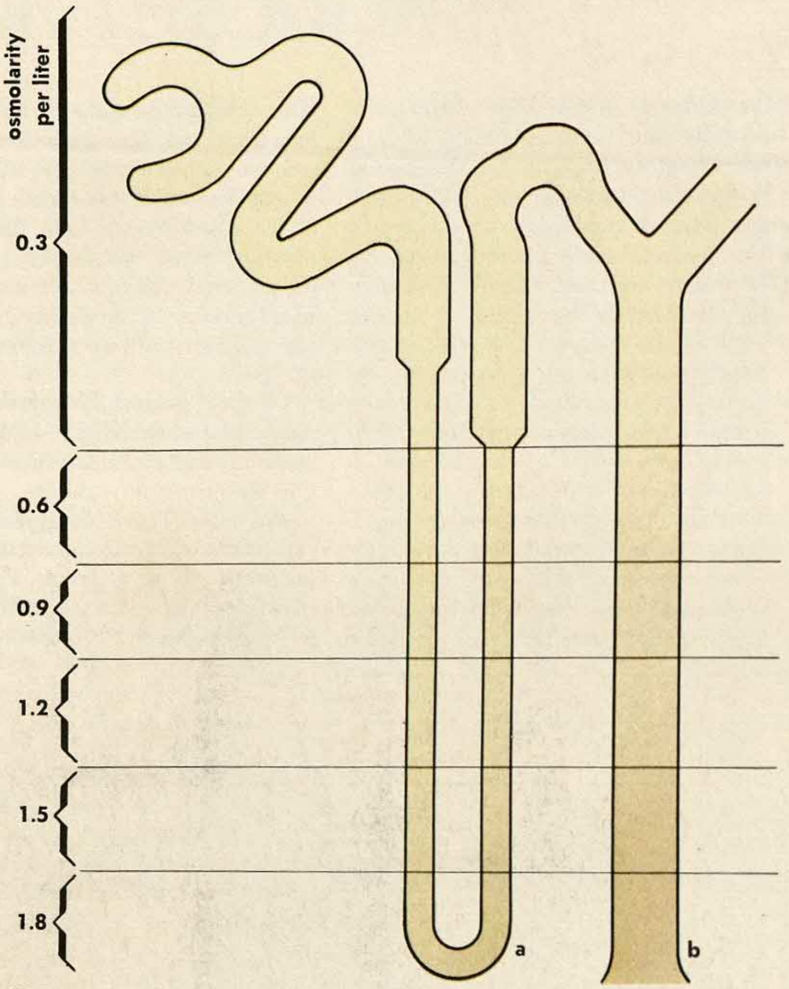
THE RENAL FILTER—The kidney, one of the most complex organs of the human body, can be considered a compound tubular gland, for it contains about a million kidney tubules (nephrons). One end of the tubule, Bowman's capsule, receives materials from the glomerulus, a tuft of blood capillaries. Bowman's capsule is a filter that permits most of the components of blood to enter the proximal tubule. Blood cells and large protein molecules are retained in the blood, but urea, glucose, salts, water, and other substances of small molecular weight pass from the blood into the hollow of Bowman's capsule. This liquid, the glomerular filtrate, then passes through the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule. These portions reabsorb much of the water, glucose, and salts that can be utilized again by the body. The capillaries that surround the convoluted tubules and the loop of Henle receive these substances and return them to the general circulation. Some additional wastes are absorbed from these capillaries to the tubules.

The water and wastes that reach the collecting tubule from the distal convoluted tubule form urine. The urine passes from the collecting tubule to the ureter, which conducts it to the urinary bladder.

the kidneys, where they branch repeatedly into small arterioles, each of which enters one Bowman's capsule. Within the capsule the arterioles branch into a tuft of capillaries, the glomerulus. This leads to another arteriole that departs from Bowman's capsule. The afferent arteriole that leads into the capsule has a larger diameter than the efferent one that carries blood away from it. Because of this, the blood in the glomerulus is under high pressure and some of its contents are forced out of the walls of the capillaries and through the innermost wall of the double-walled Bowman's capsule. The material that leaves the blood consists of water and the many water-soluble compounds present in the blood plasma—urea, glucose, salts, and other compounds. Only the large protein molecules and the blood cells cannot pass through the capillary walls and so remain behind in the blood. The work of filtering materials from the blood is thus performed by the heart, which by its pumping action maintains the high blood pressure in the glomeruli. The kidney functions in only a passive way at this point.

The fluid filtered through the glomerulus is glomerular filtrate. In addition to wastes, it contains many substances that the body can use—glucose, salts, and much water. The reabsorption of these substances is the function of the remaining portion of the nephrons. The glomerular filtrate passes through the proximal convoluted tubule, the loop of Henle,





VARIATION IN THE CONCENTRATION OF URINE AND CONSEQUENT VARIATION IN OSMOTIC PRESSURE IN THE RENAL TISSUE—The concentration of urine and the osmotic pressure in the loop of Henle **a** increase in the descending limb, are at a maximum in the curve, and gradually decrease in the ascending limb. In the collecting tube **b**, the osmotic pressure of the urine again increases. The reabsorption of water concentrates the urine to about 1 percent of the volume of the glomerular filtrate.

and the distal convoluted tubule. These parts of the nephron are surrounded by a second net of capillaries that proceed from the efferent arteriole. The glomerular filtrate contains essentially the same dissolved substances that blood plasma does and has them in the same concentrations. Under such conditions, substances would not be expected to move from one of these fluids to another; however, glucose, salts, and water do move from the tubules into the capillaries. This happens only if energy is supplied, and this energy comes from the respiration of kidney cells. If respiration is stopped experimentally in kidney tissue, reabsorption stops.

The reabsorption of water concentrates the glomerular filtrate and reduces its volume considerably. The amount of glomerular filtrate produced by two kidneys in a day varies a great deal from person to person and also with environmental conditions, but 150 liters (about 150 qts) is a common figure. Of this, all but 1 or 2 are reabsorbed into the capillaries from the convoluted tubules and the loop of Henle.

The quantity of each substance reabsorbed depends on the amount of that material present in the blood and the present need for it in the body. If much salt has been ingested, the amount of salt excreted in the urine is higher than if the salt content of the blood had just fallen. The final salt concentration in the urine depends more on the quantity that is reabsorbed in the tubules than the quantity filtered in the glomerulus.

Ordinarily, all the glucose of the glomerular filtrate is reabsorbed into the blood. If, however, the glucose content of the blood is high (more than 0.1 percent), as it is in diabetes, not all of it is reabsorbed, and some of it is excreted in the urine. The presence of glucose in the urine is one indication of diabetes.

The permeability of the nephron walls is influenced by several hormones. The antidiuretic hormone (ADH) produced by the pituitary gland acts on the walls of the distal convoluted tubule and increases its permeability, permitting the passage of water from the tubule to the capillaries and concentrating the filtrate. Aldosterone, produced by the adrenal glands, regulates the reabsorption of water.

The capillaries surrounding the nephron unite into a small vein that joins similar veins and empties into the renal vein. The renal vein carries blood from the kidney to the inferior vena cava and thus to the general circulation of the body.

In addition to permitting reabsorption of some substances, the loop of Henle and the distal convoluted tubule receive some additional wastes from the capillaries. This process is called tubular secretion, and it requires the expenditure of energy by kidney tissue.

The final concentrated filtrate is urine. It passes from the distal convoluted tubule, which receives urine from several nephrons. From the many collecting tubules of a kidney it proceeds to the ureter, which conducts it to the urinary bladder.

In the process of forming urine, the kidney performs several other functions. The excretion of the proper amounts of several substances regulates the water-salt balance in the body and maintains the proper osmotic pressure of the body fluids. It also regulates the pH of the blood by excreting or reabsorbing acids or bases. In addition to this, it produces the enzyme renin, which, through a series of reactions, causes the production of angiotonin (hypertensin). Angiotonin causes constriction of arterioles and thus regulates arterial pressure.

THE PHYSIOLOGY OF THE HEART

the cardiac cycle

The circulatory system is the transportation system of the body. It carries food, water, oxygen, minerals, and hormones to all the cells of the body; it also carries carbon dioxide and metabolic wastes away from the cells to organs that can excrete them. The larger the animal, the more important this system becomes, because the cells of a large animal can no longer be supplied by direct diffusion from the environment. The circulatory system is composed of the heart, which pumps blood by way of arteries to all parts of the body; of capillaries, where exchange of materials takes place; and of veins, which bring the blood back to the heart.

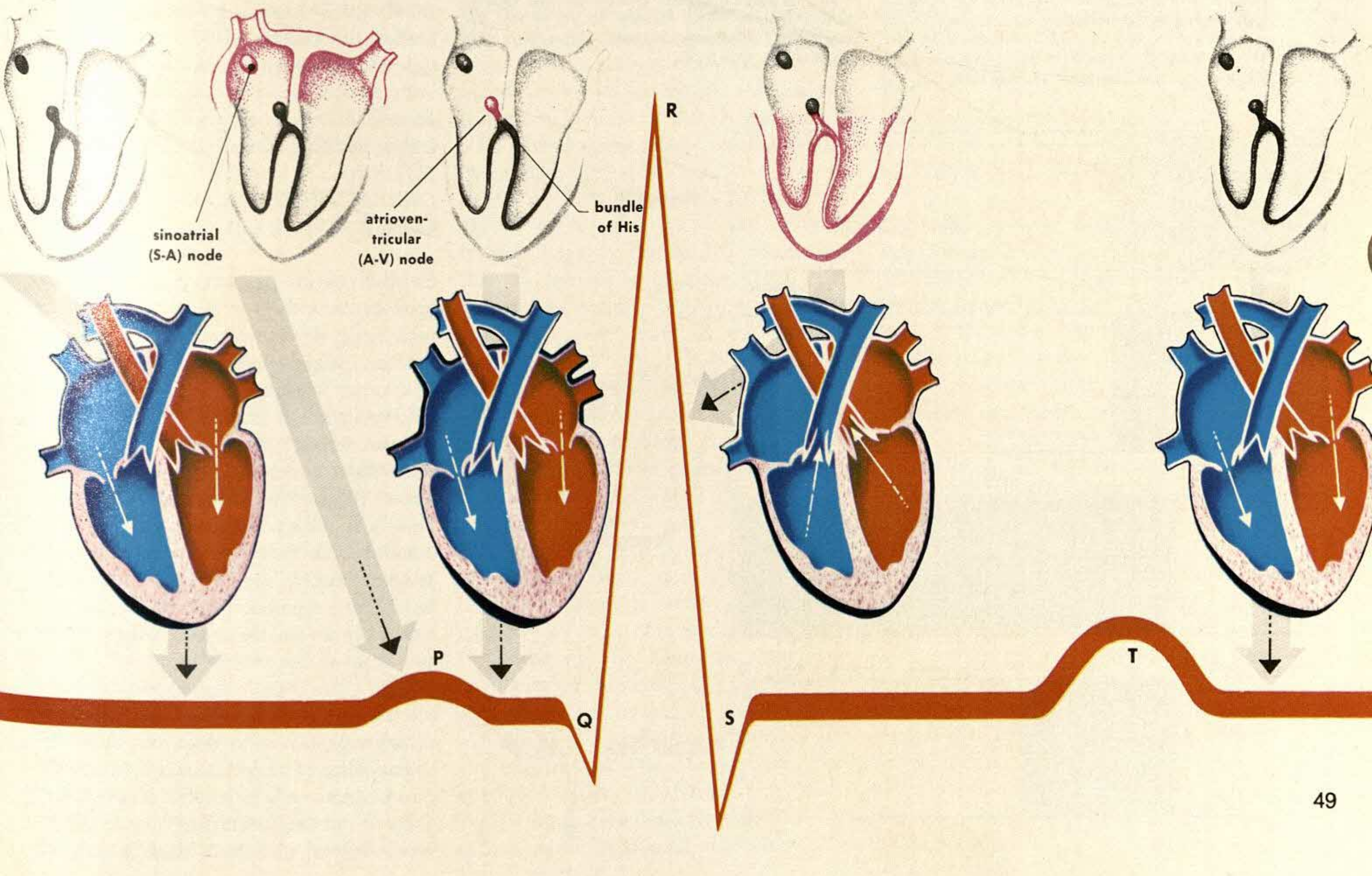
The heart operates in much the same way as does a pressure or force pump. Blood from all parts of the body except the lungs enters the right atrium (auri-

THE CARDIAC CYCLE AND THE ELECTROCARDIOGRAM—This illustration shows the relationship between the electrical and mechanical phenomena that take place during cardiac activity. The cardiac cycle consists of three phases: (1) systole of the atria; (2) systole of the ventricles; and (3) diastole. During atrial systole the two atria contract simultaneously, sending the blood into the ventricles through the open atrioventricular valves. In this first phase the ventricles are in diastole. The ventricles then contract in ventricular diastole. Initially, the muscles of both ventricles become tense without undergoing any shortening. The atrioventricular valves close—and when the pressure of the blood in the ventricles rises above the pressure in the pulmonary artery and aorta, the semilunar valves into these blood vessels open and the blood flows into them as the ventricles contract. After the ventricles are empty, the semilunar valves close; ventricular diastole follows, and a new cycle is ready to start. The contraction of the heart begins in a portion of the right atrium, the S-A node, extends to both atria, then to the A-V node, the bundle of His, and hence to both ventricles.

In 1903, the Dutch physiologist Willem Einthoven invented a machine for recording the electrical currents produced by the active heart. The modern version of this machine is the electrocardiograph (ECG or EKG), and the record that it transcribes is the electrocardiogram. The ECG is based on the well-established principle that an impulse traveling along a nerve or a wave of contraction along a muscle changes the assortment of ions on the outside and inside of the membranes. This brings about a change in the electrical potential of the cells—a change that can be observed on a galvanometer. The changes in the electrical potential in the heart during a cardiac cycle are transmitted to a galvanometer by way of electrodes applied to the surface of the skin at various parts of the body. The movements of the galvanometer needle are transferred to a recording pen that makes a continuous line on graph paper. From observing the recorded pattern of many hearts it is possible to determine the normal pattern and therefore, by comparison, to detect an abnormal pattern. The waves seen in the graph are due to the changes in the electrical potential of the heart as the wave of excitation that precedes the contraction of the muscle spreads from the S-A node throughout the heart. Any alteration in the process of conduction is immediately recorded on the ECG; hence, the great value of the electrocardiograph as a diagnostic tool.

Each wave on the graph corresponds to a change in the electrical potential of a different part of the heart. The P wave just precedes the contraction of the atria and so is due to the wave of excitation of that part of the heart. After a brief pause, the wave of excitation spreads over the ventricles, appearing as the QRS-complex wave. The T wave represents the period of ventricular recovery.

1



cle). The return of the blood to the heart is due to: (1) the pressure of massaging action of skeletal muscles on the large veins; (2) the pressure from the contraction of the left ventricle—a pressure slightly diminished by its passage through arteries and capillaries; and (3) the suction of the expanding right atrium, which tends to pull the blood into the dilated atrium. From the right atrium the blood goes to the right ventricle and thence to the lungs by way of the pulmonary artery. In the lungs carbon dioxide is lost and oxygen is picked up. The oxygenated blood goes back to the heart, entering the left atrium by way of the pulmonary vein. From the left atrium the blood goes to the left ventricle, which pumps the blood to all parts of the body except the lungs. From the capillaries the blood enters the veins and then moves back to the right atrium, thus completing one round trip. During the trip carbon dioxide, which the blood has picked up from all cells, is exchanged for oxygen, which is taken to all cells; digested and absorbed food and water is carried to all cells, and urea and other waste products of metabolism are taken to the kidneys for excretion. In order to keep the blood moving regularly through the system, the heart is equipped with a number of important characteristics.

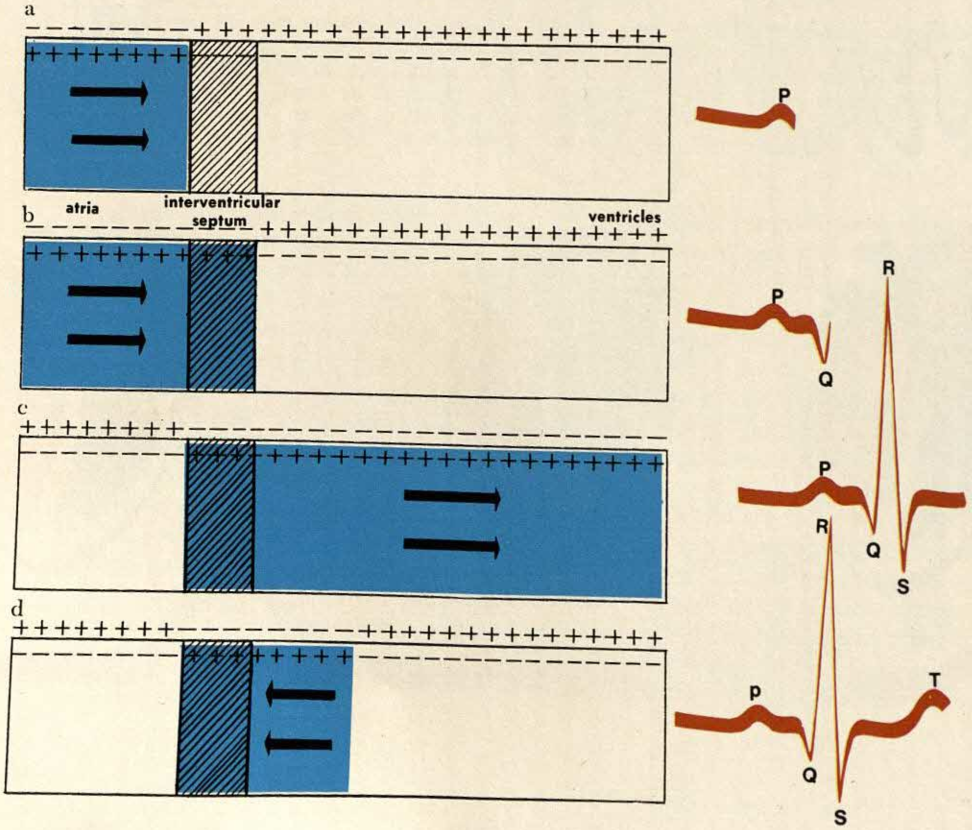
HOW THE HEART IS ADAPTED TO ITS FUNCTION

Like any pump, the heart has reservoirs (accumulating chambers), propulsive parts, valves to prevent backflow, and control devices. The two reservoirs or receiving parts of the heart are the left and right atria (also known as auricles), which have relatively thin muscular walls. The forwarding or propulsive parts of the heart are the left and right ventricles, which have thick muscular walls. Pocketlike valves that prevent backflow are located between the left atrium and left ventricle, between the right atrium and right ventricle, and at the points where the large arteries and veins enter and leave the heart. In mammals, the two sides of the heart are separated by a partition, so that the mammalian heart is a double pump with no connection between the two sides. The right side carries venous (unoxygenated) blood; the left side carries arterial (oxygenated) blood. The control mechanism consists of modified heart tissue (the myogenic control) and nerves (the neurogenic control).

The microscopic structure of heart tissue is also adapted to its function. Cardiac muscle, like the muscle attached to the skeleton, consists of long, multinucleated cells with conspicuous cross striations. Cardiac muscle, however, differs from skeletal striated muscle in that the fibers (cells) branch, rejoin, and interlace. Moreover, they are arranged spirally in sheets around the ventricles; the sheets are separated by fibrous tissue. The walls of the two ventricles, particularly the left, are considerably thicker than the walls of the two atria. The muscle fibers of the atria are not continuous with those in the ventricles, but the fibers of the two atria are continuous with each other, as are the fibers of the two ventricles. Histologically, the myogenic control system or impulse-conducting system looks something like cardiac muscle, except that the striations are less clear and more cytoplasm is visible. The myogenic control system consists of two main parts: the sinoatrial node (S-A node), also called the pacemaker, located at the point where the large vein from the head enters the right atrium; and the atrioventricular node (A-V node), located posteriorly in the wall between the left and right atria. Bundles of modified cardiac muscle (called the bundle of His) extend from the A-V node into the cardiac muscle of both ventricles. The modified cardiac muscle fibers of nodes and bundles are called Purkinje fibers.

2

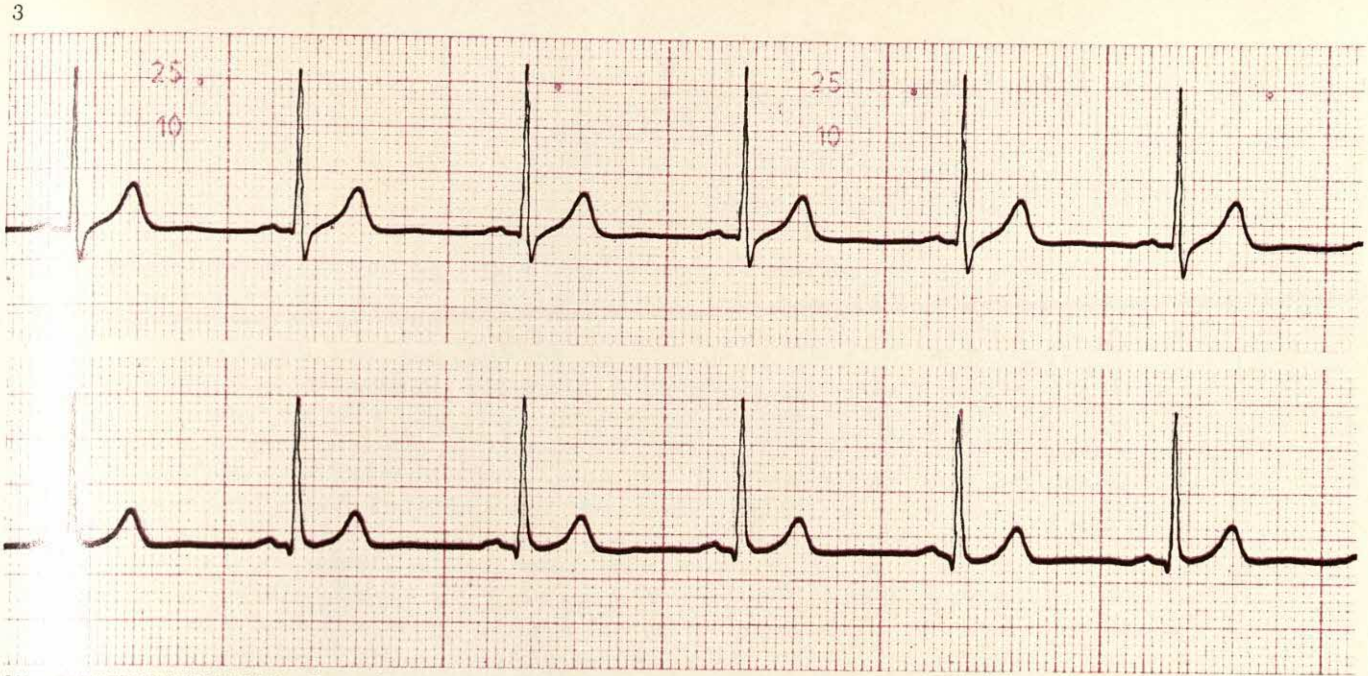
PROPAGATION OF THE IMPULSE IN CARDIAC TISSUE—This illustration shows the electrical activity that takes place in the heart as a wave of excitation travels over it. In Illustration 2a the impulse has traveled over the atria while the rest of the heart is at rest. The P wave is formed at this time. In Illustration 2b the impulse is traveling to the atrioventricular node, which shows as the Q wave. In Illustration 2c the impulse has reached the ventricles by way of the branches from the bundle of His. The ventricular excitation shows as QRS. Illustration 2d shows the ventricles returning to rest, shown as the T wave on the ECG.



CHARACTERISTICS OF CARDIAC CONTRACTION

Cardiac rhythm has always been considered as an indicator of life and of the well-being of an animal. The complete cardiac cycle includes systole (the contraction or working phase), diastole (the dilation phase), and a period of rest. In man at rest, the cycle lasts a little more than a second, the heart beating about 72 times a minute. The rate of heartbeat varies with age, sex, weight, amount of activity, and the emotional state of the individual. Other mammals have their characteristic rates—25 per minute in an elephant and 125 per minute in a rat, for example.

Like other muscle tissue, cardiac muscle obeys the all-or-none law; that is, it either contracts or it does not. An individual fiber of skeletal or cardiac muscle cannot contract partially; it contracts fully or not at all. Cardiac muscle differs from skeletal muscle in that because of



AN ELECTROCARDIOGRAM—The electrocardiograph machine (ECG or EKG) makes a record called the electrocardiogram. A normal pattern is shown in the illustration. The first ECG tracing from man was obtained in 1887 through the use of a capillary electrometer. In 1903 Willem Einthoven obtained tracings almost identical to modern ones by using a string galvanometer.

its branching, rejoining, and interlacing characteristics, the two atria form a single muscle; the same holds true for the two ventricles.

Cardiac muscle, again like other muscle tissue, has a refractory period during which it cannot contract. If a ventricle is stimulated electrically during systole, no response occurs to that stimulus. If, however, the stimulus is applied during diastole when the ventricle is resting, the muscle will respond with an extra systole followed by a longer than normal diastole called the compensatory pause. Cardiac muscle, therefore, is not irritable (is not able to respond to a stimulus) when contracting; this is the refractory period.

If tension is exerted on skeletal or cardiac muscle so that it is stretched, it will contract more forcibly than normally. When the large muscles of the body contract during exercise, more blood is propelled back to the right atrium by the squeezing action of the body muscles on the large veins. A greater quantity of blood coming to the right atrium during exercise means a greater stretching of the right atrium and right ventricle, and hence a more forcible contraction. Thus, more blood is sent to the lungs—an important adaptation that provides more oxygen for working muscles of the body. This is Starling's law of the heart.

Perhaps the most remarkable property of cardiac muscle is its automaticity, that is, its ability to contract rhythmically without the stimulus of a nerve impulse. This automaticity has been established by observation and by experiment.

Frog and turtle hearts continue beating for many hours after they have been removed from the animals' bodies, provided they are kept in physiological salt solution.

Various factors that affect the rate of the heartbeat by affecting the pacemaker or cardiac muscle directly are temperature, carbon dioxide content of the blood, acidity of the blood, and concentrations of several of the hormones.

The neurogenic center of heart control is located at the base of the brain in the medulla oblongata. The function of the nerves that go to the heart is more to regulate the rate of contraction than to initiate or propagate the contraction. Branches of the autonomic nervous system originate in the medulla and terminate at the pacemaker (S-A node). The vagus nerve (part of the parasympathetic nervous system) slows the rate of contraction, while branches from the sympathetic nervous system accelerate the heart rate. The vagus is probably the chief regulator. Acting as a brake, it can have a greater or lesser decelerating effect, depending on how strongly it counteracts the more constant speeding effect of the sympathetic nervous system. The heart-rate center in the brain is affected by many body sensations and by many emotional or psychological situations. A number of physiological situations also affect the heart-rate center. If the large veins entering the right atrium are stretched due to an increase in the amount of blood returning to the heart during exercise, sensory nerves carry the stretch stimulus to the heart-rate center, which sends an accelerator impulse to the pacemaker over the sympathetic nervous system. The heart then beats faster, sending more blood out of the aorta. Sensory impulses in the aorta then go to the heart-rate center, which sends braking impulses to the pacemaker, thus slowing the heart. Thus, the speed of the heart is automatically adjusted to the volume of blood entering the heart.

NUTRITION OF THE HEART

Like other muscle, heart muscle must have adequate supplies of food and oxygen. These are brought to the heart not by the blood that is being pumped through the heart, but by blood carried to the heart by the coronary artery, which branches off the aorta and extends into the cardiac muscle. Here the artery breaks up into capillaries and eventually leads back to the coronary veins, which empty into the right atrium. Food for cardiac muscle is the same as for other tissues except that lactic and pyruvic acids from the breakdown of glucose in the skeletal muscle are particularly important. To metabolize these acids, oxygen must be present; hence the extreme importance of oxygen for the proper functioning of cardiac muscle. If oxygen is in low supply, coronary blood vessels dilate, thus increasing the circulation to the heart muscle and hence increasing the amount of oxygen brought to the muscle.

THE CIRCULATORY SYSTEM

the heart, arteries, capillaries, and veins

Two requirements of any living cell are the acquisition of nutrients and the disposal of waste products. In large multicellular organisms, most of the individual cells are not capable of performing these functions independently. In humans and other large animals, the circulatory system carries these substances to and from the tissue cells. The blood receives food from the intestine and oxygen from the lungs and distributes them to tissues that require them. At the same time, the blood accepts waste products and carries them to the kidneys, lungs, and skin, from which they are excreted.

The circulatory system of the human body is a closed one; the blood is confined to cylindrical vessels and the heart, which pumps blood through the vessels that penetrate nearly all the tissues of the body. Arteries are the vessels that conduct blood away from the heart. They branch into finer and finer arteries. Those that are so small that they cannot be seen with the unaided eye are called arterioles. These branch into even finer vessels called capillaries.

Nearly every part of the body is served by capillaries, for it is through the capillary walls that the essential exchange of materials occurs between the blood and the various tissues. The total surface area of the capillaries of an adult human being is about 6,300 m^2 (about 7,500 yd^2).

The capillaries anastomose with each other, forming a network or bed of capillaries. The blood leaving a capillary bed begins its trip back to the heart by entering a new set of vessels, the venules. Like the arterioles, these are small vessels that cannot be seen with the naked eye. Venules unite into small veins, and these unite into larger and larger veins, the final veins emptying into the heart.

The heart is an organ composed of four chambers, the walls of which are highly muscular. The two upper chambers are called atria or auricles; the two lower chambers are the ventricles. An opening permits blood to flow from the right atrium to the right ventricle, and another opening allows movement from the left atrium to the left ventricle; in the mature heart, however, there is no direct communication between the chambers of the right side and those of the left side. The right atrium and ventricle pump spent blood low in oxygen from the various parts of the body to the lungs, and the left atrium and ventricle pump oxygenated blood from the lungs to the rest of the body. The heart thus may be considered two pumps lying side by side. In one complete circuit around the body, blood passes through the heart twice, once through the lungs, and once through one other part of the body.

Spent blood from the body enters the right atrium of the heart and passes to the right ventricle. Between these two chambers, a valve prevents the flow of blood backward from the ventricle to the atrium. Because this valve is composed of three large cusps, it is called the tricuspid valve.

The artery leaving the right ventricle is the pulmonary trunk. It, too, is supplied with a valve, the pulmonary valve, which prevents backward flow. The pulmonary trunk branches into the right and left pulmonary arteries, which proceed toward the right and left lungs, respectively. Each pulmonary artery branches into smaller arteries called arterioles, and then into the capillaries that release carbon dioxide into the alveoli of the lungs and absorb oxygen.

The oxygenated blood then travels through the venules and small veins that unite into the right and left pulmonary veins. These empty their contents into the left atrium of the heart. A bicuspid valve (also called the mitral valve) permits blood to flow from the left atrium to the left ventricle.

Departing from the left ventricle is the aorta, the largest artery of the body. The aorta rises upward from the ventricle, then curves and descends downward through the trunk. The three parts of the aorta are the ascending aorta, the aortic arch, and the descending aorta. From the aorta, arteries branch off that serve all the organs of the body except the lungs. On any round trip through the body, the blood usually goes through only one set of capillaries in only one organ. Blood going to the brain, for example, does not reach the kidneys or the stomach or the muscles of the arm without first returning to the heart.

Arising from the ascending aorta are the coronary arteries, which branch into the muscle of the heart. The heart muscle is so thick and so active that it cannot be served adequately by the blood that flows through the heart chambers. Heart attacks are caused by the obstruction of coronary arteries.

From the aortic arch, three large arteries branch off: the innominate artery (which divides into the right common carotid and the right subclavian arteries); the left common carotid artery; and the left subclavian artery. The carotid arteries serve the head and neck, and the subclavian arteries serve the arms.

The many branches of the descending aorta serve the organs of the thorax and the abdomen. The descending aorta also branches into the two common iliac arteries, which serve the legs. Two of the abdominal arteries are the mesenteric arteries, the capillaries of which lie in the intestinal walls and absorb digested food. Unlike most other capillaries, these do not empty into veins that lead to the heart; rather they empty into the hepatic portal system, which leads to the liver, where some of the food is deposited or further processed. The renal arteries have a special function; they carry urea, a waste product of metabolism, to the kidneys. Here the urea is removed from the blood.

For most arteries there are corresponding veins that collect blood from the several organs of the body. The blood eventually is returned to the right atrium through either of two large veins: the superior vena cava, which receives blood from the head, arms, and thorax; and the inferior vena cava, which collects blood returning from the abdomen and the legs.

Blood does not travel through the heart in a smooth continuous stream. Because the two atria contract simultaneously and the two ventricles contract immediately thereafter, blood enters the arteries in spurts. Because the arteries near the heart are elastic, the flow of blood becomes smoother, and the pulse becomes less and less noticeable with distance from the heart. In the capillaries and in the veins, no pulse is noticeable.

Although the diameters of individual arteries decrease with distance from the heart, the total cross-sectional area increases because there are so many more

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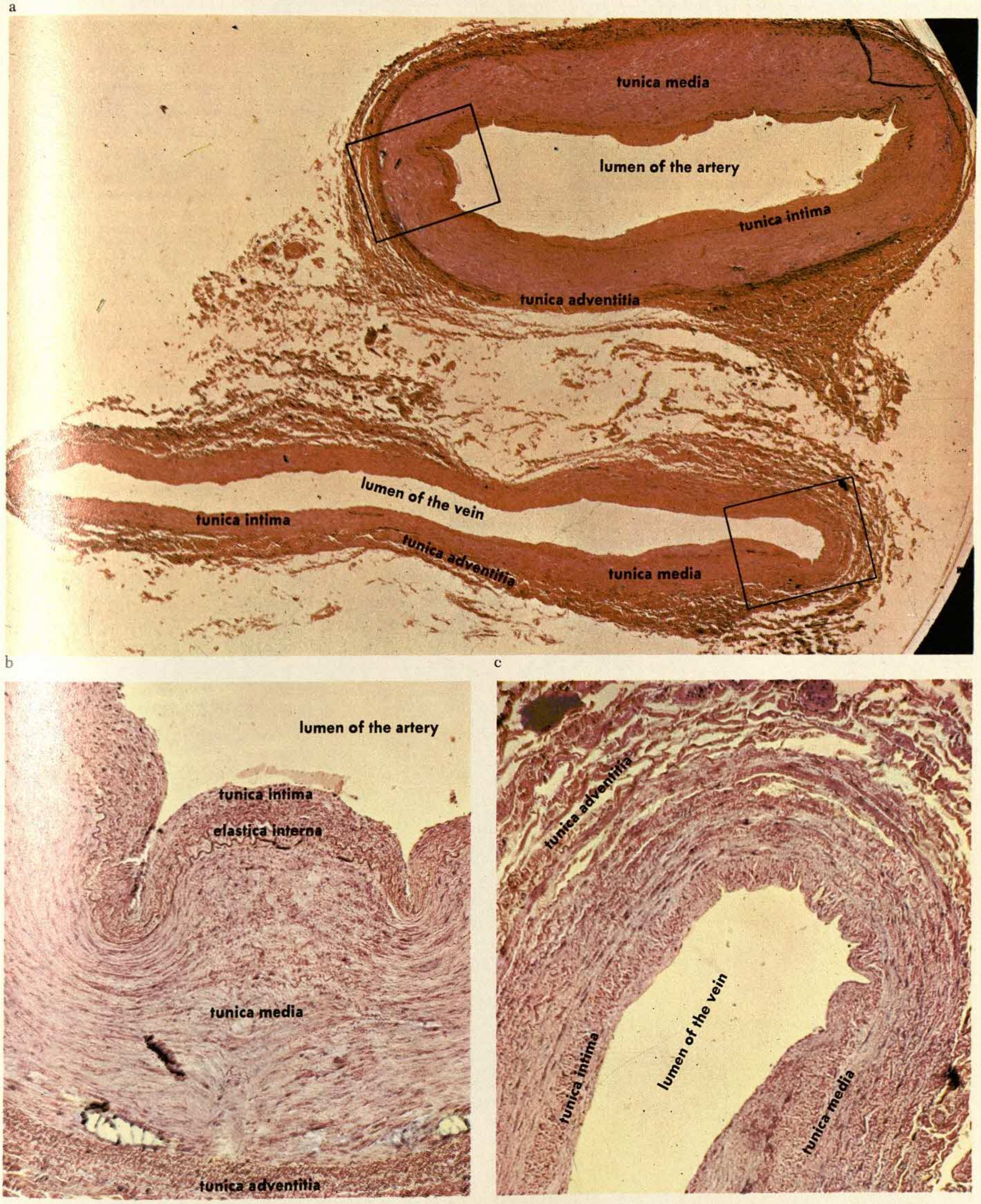

ARTERIES AND VEINS IN TRANSVERSE SECTIONS—Illustration 1a shows a transverse section of an artery and a vein, photographed under the microscope. (25 X) The artery has a thicker wall than the vein, and the lumen of the vein is narrower and more elongated. Illustration 1b shows a detail of the artery from the previous illustration. (80 X) Illustration 1c shows a detail of the vein from Illustration 1a. (80 X)

The walls of the larger arteries have a great deal of elastic tissue. These arteries are those near the heart—the pulmonary arteries, the aorta, the innominate subclavian, and the carotid arteries. These arteries expand and contract with the discontinuous flow of blood from the beating heart and convert it to a continuous flow. Smaller arteries have muscular walls. Veins have walls thinner than arteries of the same size, and they have fewer muscles or none. Because of this, veins collapse when blood pressure is very low and they usually appear to be flattened in microscope preparations. Valves in the veins prevent blood from flowing backward.

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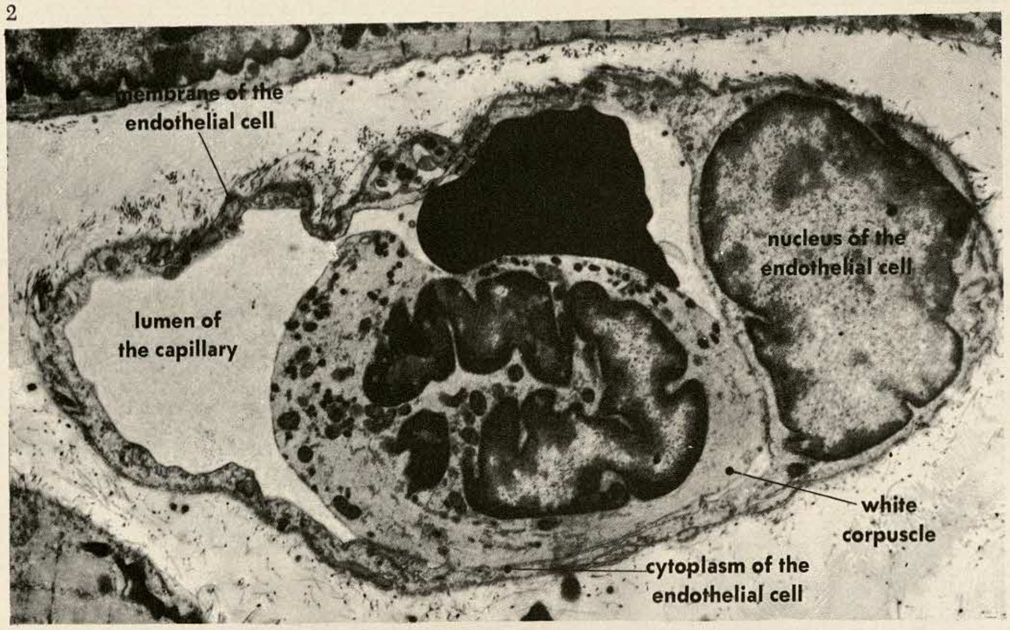
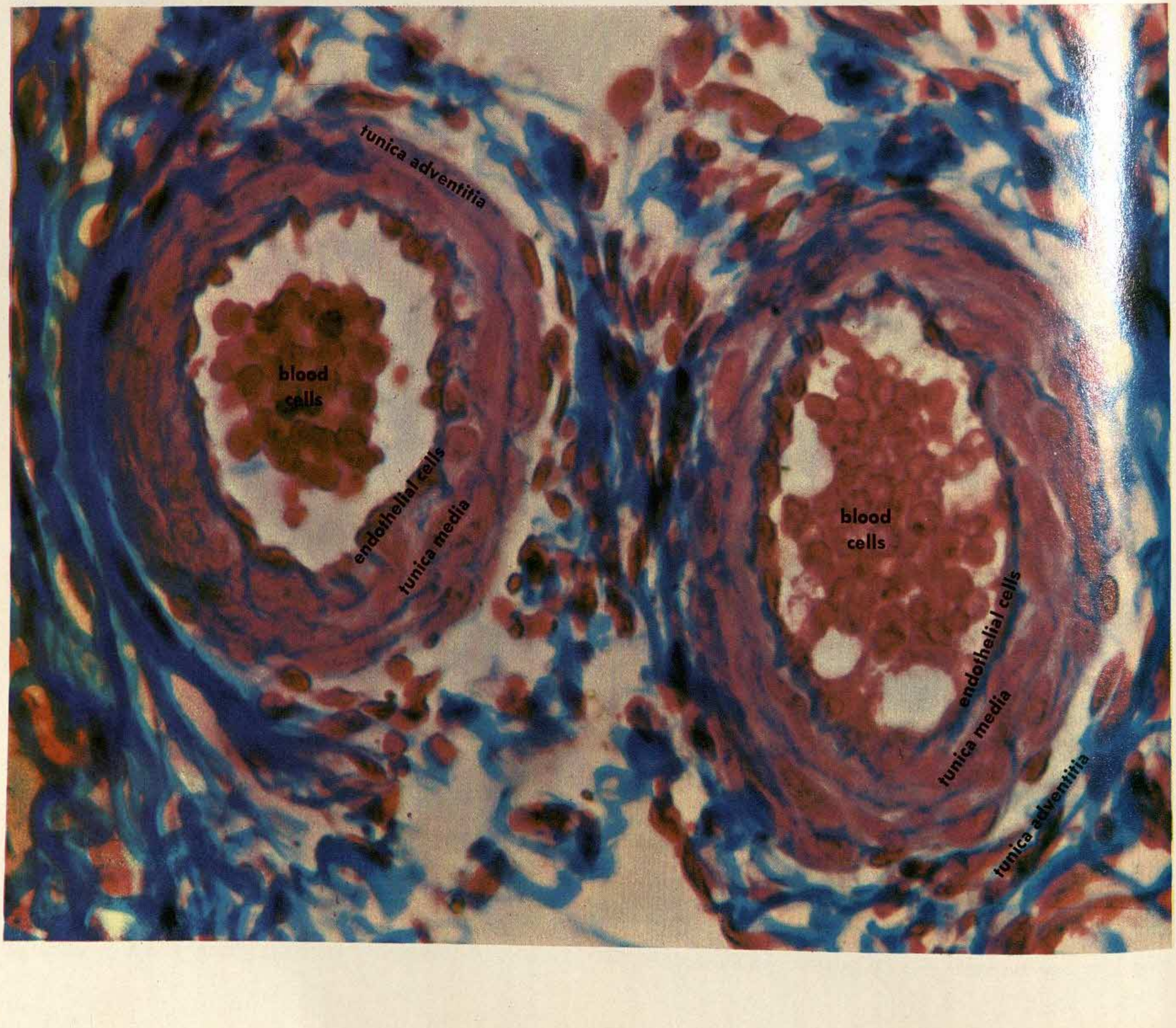


A CAPILLARY UNDER THE ELECTRON MICROSCOPE—This photograph shows a transverse section of a capillary. A red and a white corpuscle can be seen inside it. Also visible at one end is the nucleus of one of the endothelial cells that line the lumen of the capillary. (20,000 X)

THE ARTERIOLES—This photograph shows a transverse section of two arterioles. The tunica intima is constituted of endothelium connective tissue and an internal elastic lamina; the tunica media is constituted mostly of smooth muscle cells; and the tunica adventitia is made up of connective tissue. Many blood cells are visible in the interior. (200 X)

3



arteries. The maximal cross-sectional area occurs in the capillaries. The speed with which blood moves decreases as the cross-sectional area increases. The velocity of blood is lowest in the capillaries, thus permitting more nearly complete exchange of materials between the blood and the tissues served. As the blood returns to the heart, its velocity increases again, because the total cross-sectional area of the veins decreases with nearness to the heart.

Blood pressure drops gradually as the blood travels from the heart through the arteries. It falls abruptly when the blood enters the capillaries and then continues to decrease gradually until the blood reaches the heart.

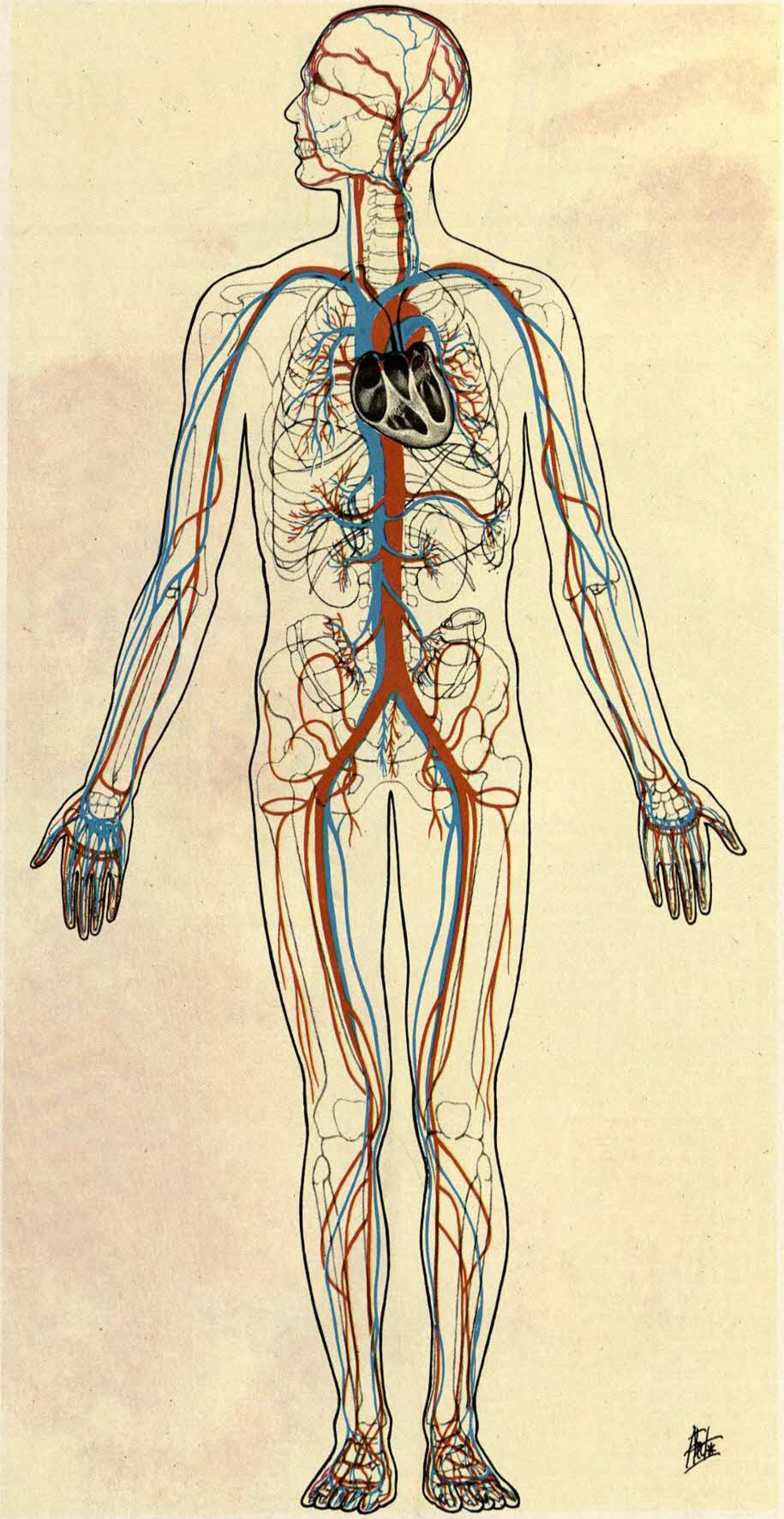
The walls of the larger blood vessels consist of three major parts. The tunica intima lies adjacent to the lumen of the vessel. The tunica media is next, and the tunica adventitia is the outermost layer. The tunica intima may consist of three layers: an inner endothelium, connective tissue, and the elastica interna, the latter containing elastic fibers. The tunica media contains smooth muscle, the fibers of which encircle the vessel; elastic fibers of connective tissue may also be present. The tunica adventitia is a covering of connective tissue; in the larger vessels it contains nerves and smaller blood vessels.

The exact composition of the vessel wall varies with the particular vessel. The aorta, the pulmonary, innominate, subclavian, and common carotid arteries are elastic arteries; their walls contain a high proportion of elastic fibers. The other arteries are muscular arteries with well-developed circular smooth muscle. Muscular arteries expand or contract as the need arises. The inner endothelium lines the lumen of all blood vessels and the heart. In the capillaries, the inner endothelium may be the sole constituent of the wall.

Veins have thinner walls and less muscle than arteries of comparable size. Movement of blood in veins is due in part to the contraction and relaxation of muscles near the veins. This contraction and relaxation is very important in veins of the legs, especially when a person is in a vertical position. Veins are equipped with valves that prevent blood that has been raised from falling downward under the effect of gravity.

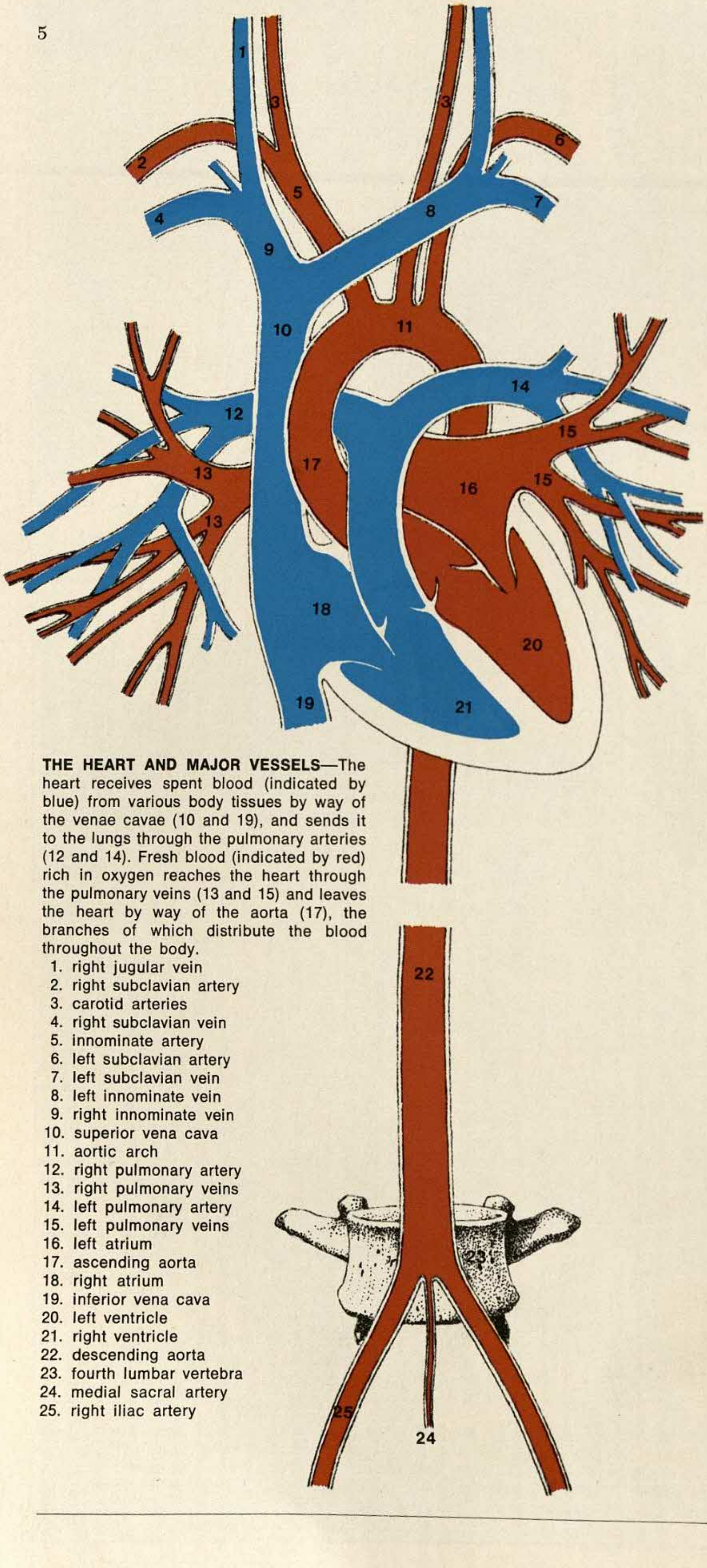
The commonest disease of the heart and blood vessels is atherosclerosis. In this condition, the walls of the arteries thicken, narrowing the passageway and decreasing blood flow. If the coronary arteries are affected, obstruction of flow to the heart muscle can be fatal.

4



THE CIRCULATORY SYSTEM—The diagram shows the heart and the larger arteries and veins of the human body. The function of the circulatory system is that of distributing nutritive substances and oxygen to the various tissues of the body and of carrying away their waste products, which are then eliminated by other organs. The heart is a muscular organ that pumps the blood through the arteries and veins.

5



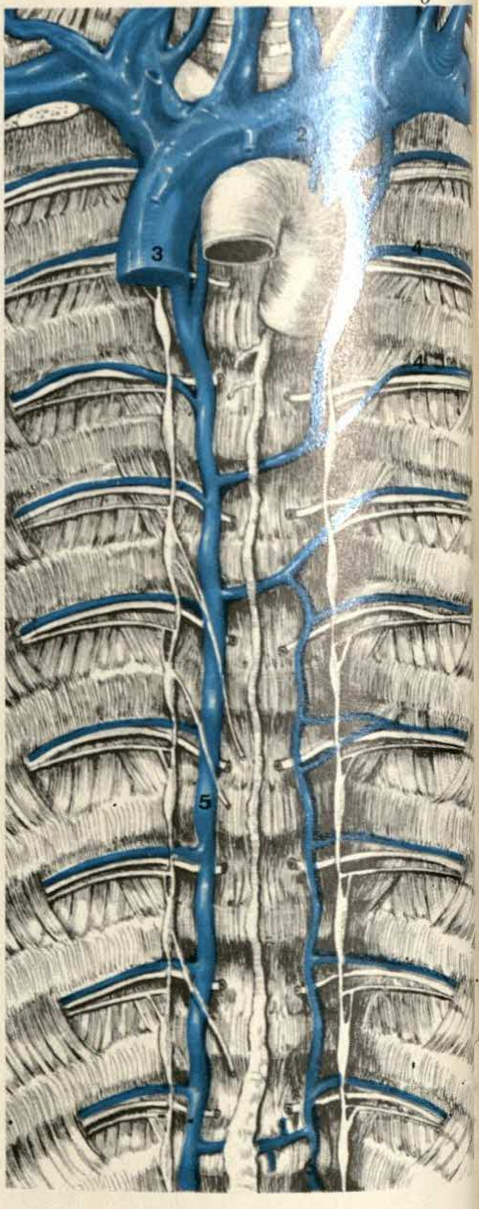
THE HEART AND MAJOR VESSELS—The heart receives spent blood (indicated by blue) from various body tissues by way of the venae cavae (10 and 19), and sends it to the lungs through the pulmonary arteries (12 and 14). Fresh blood (indicated by red) rich in oxygen reaches the heart through the pulmonary veins (13 and 15) and leaves the heart by way of the aorta (17), the branches of which distribute the blood throughout the body.

1. right jugular vein
2. right subclavian artery
3. carotid arteries
4. right subclavian vein
5. innominate artery
6. left subclavian artery
7. left subclavian vein
8. left innominate vein
9. right innominate vein
10. superior vena cava
11. aortic arch
12. right pulmonary artery
13. right pulmonary veins
14. left pulmonary artery
15. left pulmonary veins
16. left atrium
17. ascending aorta
18. right atrium
19. inferior vena cava
20. left ventricle
21. right ventricle
22. descending aorta
23. fourth lumbar vertebra
24. medial sacral artery
25. right iliac artery

THE VEINS OF THE THORAX—Most of the veins of the anterior part of the thorax empty into the innominate veins, which in turn flow into the superior vena cava. The intercostal veins of the right side of the body empty into the azygous vein, and most of those of the left side empty into the hemiazygous vein.

1. left subclavian vein
2. left innominate vein
3. superior vena cava
4. intercostal veins
5. azygous vein
6. hemiazygous vein

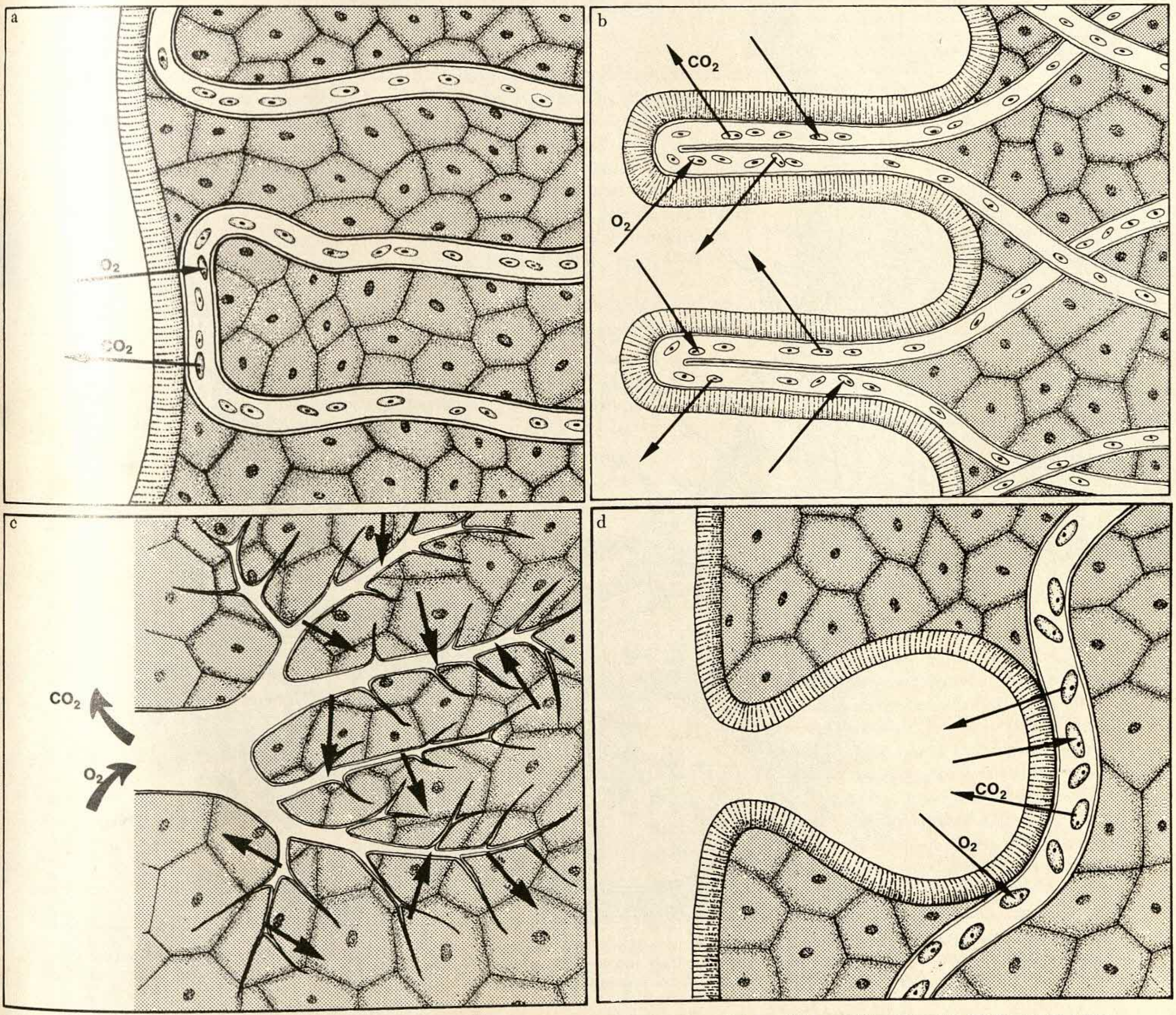
6



THE PHYSIOLOGY OF RESPIRATION | a vital function

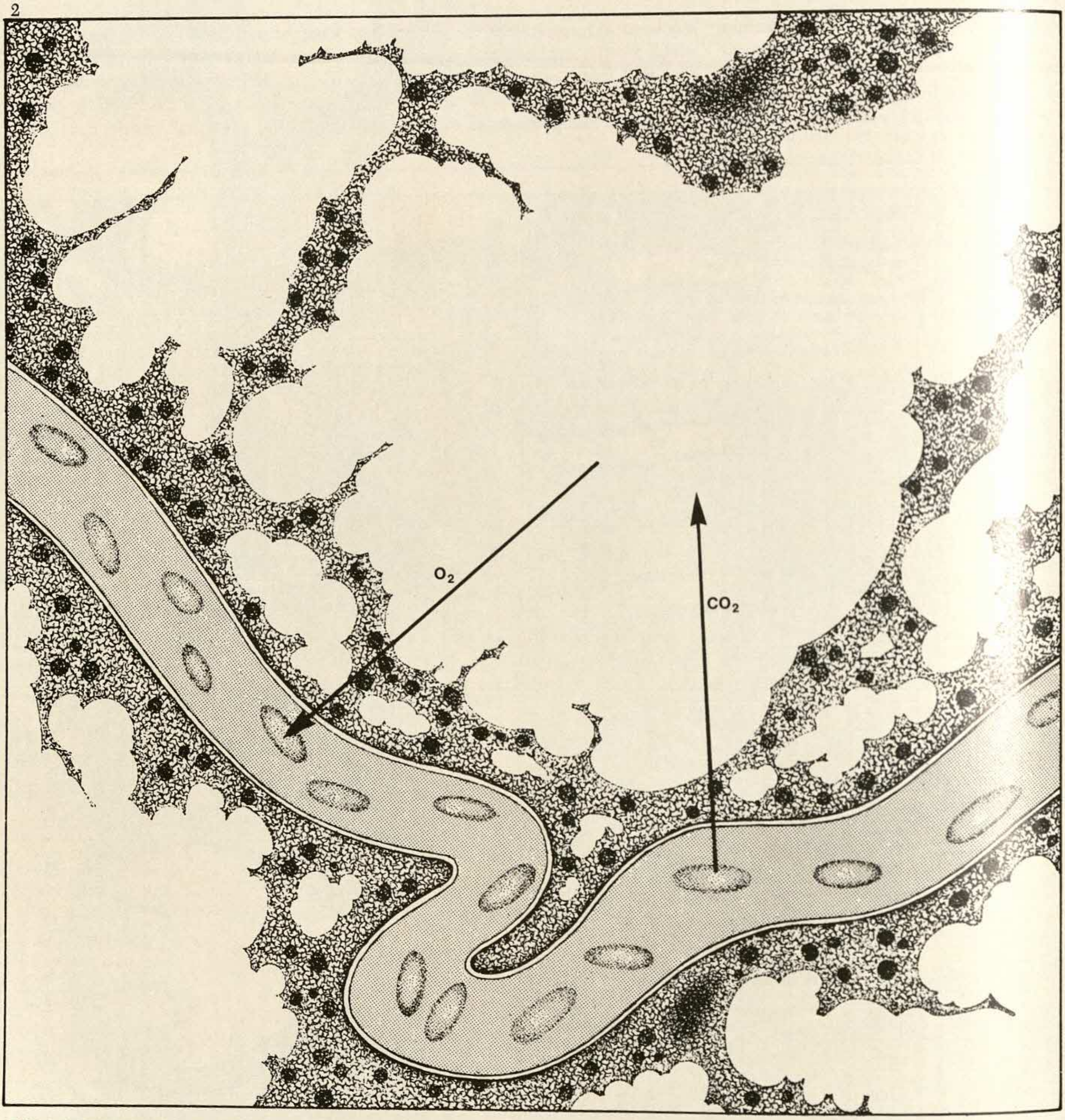
Respiration—a word of several meanings —refers to a biochemical reaction peculiar to living cells, to the exchange of gases between living things and their environment, and to breathing movements. Biochemical respiration is the process by which food is oxidized and releases energy that living organisms use not only in growth and in repair of tissues, but also in the maintenance of cells in the living state. In nearly all animals and plants, biochemical respiration requires the gas oxygen (O_2). Aquatic organisms utilize the oxygen dissolved in water. Terrestrial organisms obtain it as a gas

1



GAS EXCHANGE—Small aquatic animals have no special respiratory organs but exchange gases through the epidermis, as shown by the diagram for Illustration 1a. Fish and many other aquatic animals have gills (Illustration 1b). Insects respire by means of tracheal tubes (Illustration 1c). The diagram in Illustration 1d shows how mammals, reptiles, birds, and adult amphibians breathe by means of lungs. The arrows in the diagrams indicate the direction of movement taken by the oxygen and carbon dioxide.

2



THE PULMONARY ALVEOLI—The pulmonary alveoli (a detail is shown here) are the terminal blind sacs of the lungs. They provide optimum conditions for respiratory interchange. Their walls are monocellular, and oxygen from inspired air crosses only this thin barrier and the wall of the adjacent capillary of the circulatory system before reaching the blood.

from the air, but it ordinarily becomes dissolved in the water in living cells.

A second meaning of the word *respiration* is used only for those animals that have circulatory systems. It refers to the exchange of oxygen and carbon dioxide between the external environment and the blood and between the blood and living tissue cells. The absorption of oxygen from the environment by the blood and the release of the waste product carbon dioxide to the environment from the blood is called external respiration. The release of oxygen from the blood to tissue cells and the absorption of carbon dioxide from these cells is called internal respiration.

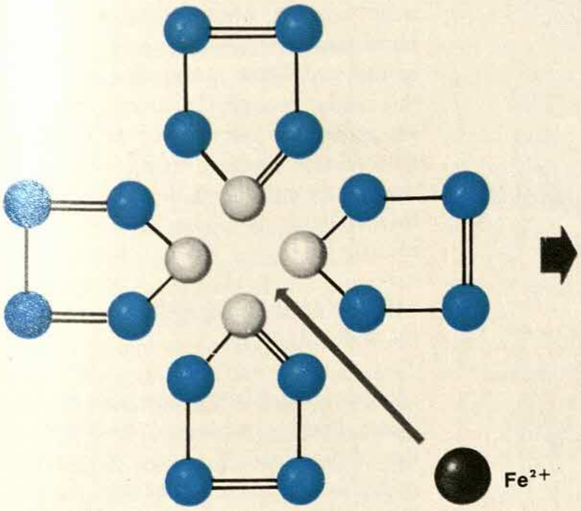
The third meaning of respiration is applied to the breathing movements of those animals that have lungs. These animals require more oxygen than could reach the blood supply of the lungs merely by diffusion; therefore, coordinated muscular movements must force air into and out of the lungs. The taking of air into the lungs is called inspiration, and the release of air from the lungs is called expiration.

SOME RESPIRATORY SYSTEMS OF ANIMALS

The simplest of animals have no special respiratory systems. In unicellular animals, the entire surface of the cell is in contact with the environment, and an ample supply of oxygen can diffuse across the cell membrane and into the cell. Similarly, carbon dioxide can diffuse out of the cell quickly enough that a harmful concentration does not build up within the cell.

HEMOGLOBIN—This figure shows a structural model of a heme molecule. It consists of four pyrrole groups around a central atom of iron. A hemoglobin molecule consists of four heme molecules in combination with a protein (globin).

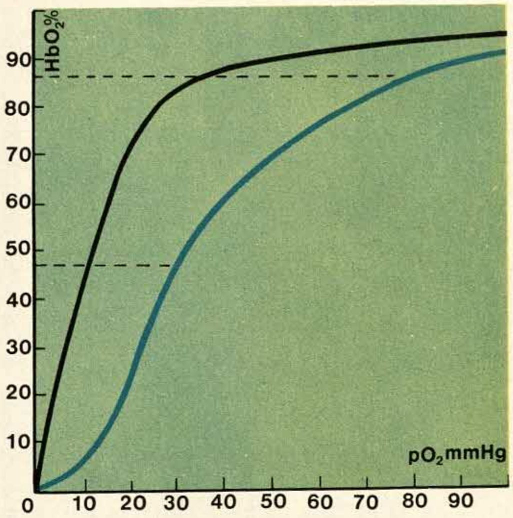
3



Very small multicellular animals, especially inactive ones, have no need for respiratory organs either; but those that have circulatory systems often have capillaries (the smallest of the blood vessels) under the epidermis. The blood runs so near the surface of the animal that it usually is separated from the environment by only two layers of cells: the epidermis and the walls of the capillaries. Oxygen absorbed by these capillaries is carried by the blood to the inner tissues.

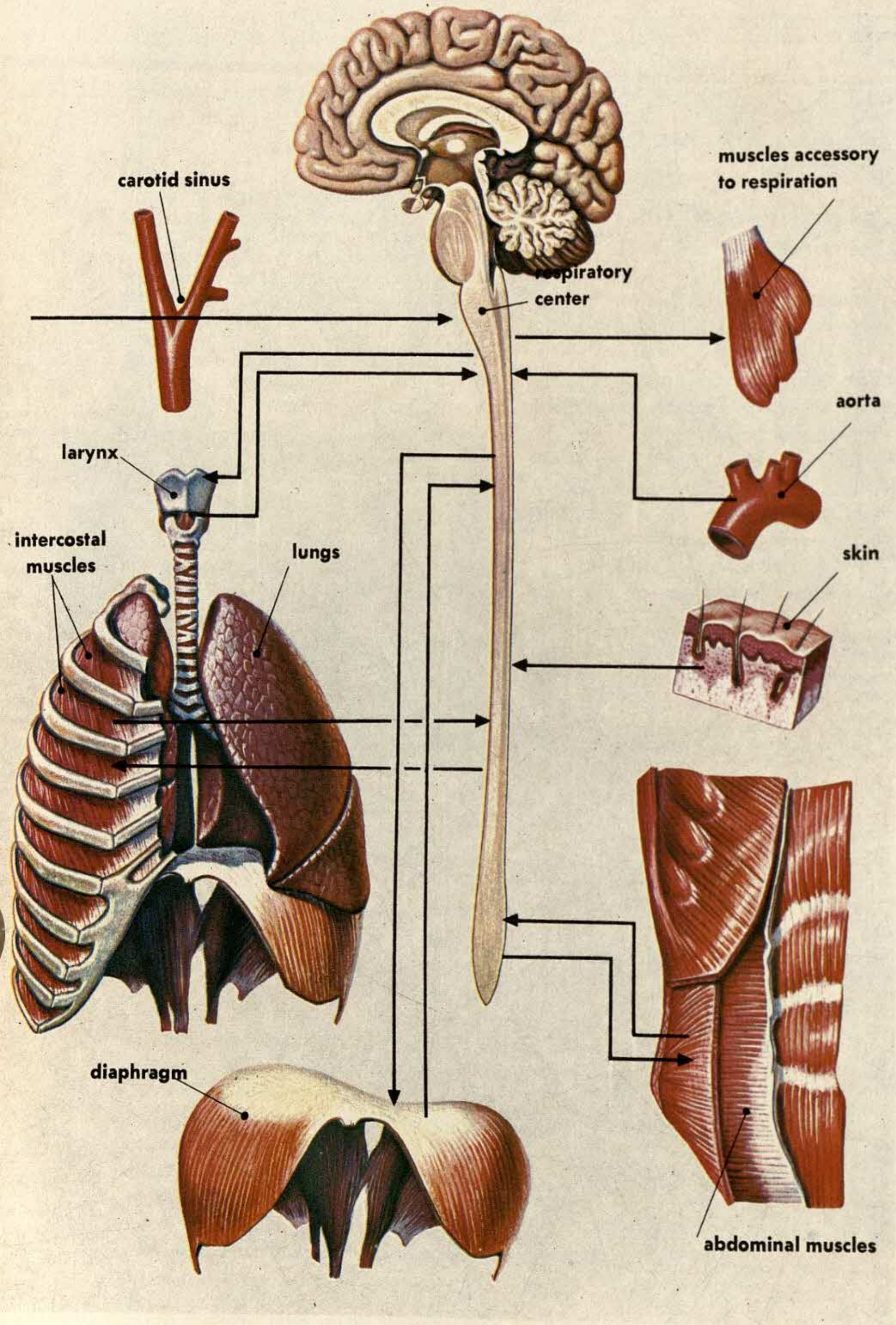
OXYGEN DISSOCIATION CURVES OF HEMOGLOBIN—Shown are the dissociation curve of hemoglobin as a function of oxygen (blue line), and the same reaction based on physiochemical laws (black line). At 30 mm Hg (actual tissue pressure), 40 to 50 percent of the hemoglobin is saturated. If hemoglobin followed physiochemical laws, 80 to 90 percent would already be oxygenated, and only a small part would perform its function.

4



Large or active animals require much more oxygen than can be absorbed through the unmodified external surface of the body. Fish and many other aquatic organisms have special respiratory organs called gills, which are bathed by water constantly. Gills are well supplied with

5



THE REGULATION OF BREATHING—The control of breathing is complex. Nervous impulses coming from several parts of the body are received by the respiratory center (motor nerve cells in a crisscrossing matrix of nerve fibers) in the medulla oblongata.

blood capillaries, and here, too, the blood flows very near the surface. A fish's gills absorb much more oxygen and release much more carbon dioxide than could its skin even if it were not covered with scales. Gills are suitable only in aquatic or moist environments, for if their great surface area were exposed to winds, they would soon dry out and become nonfunctional.

Terrestrial insects breathe by means of tracheal tubes. These branching tubes open to the outside by a few openings called spiracles, and they ramify throughout much of the body. Thus they allow oxygen to reach tissue cells, but they do not permit much loss of water from the body by evaporation.

Nearly all large, active, terrestrial organisms breathe by means of lungs. They include mammals, birds, reptiles, and many adult amphibians. Even those mammals like whales that have reverted to life in the water have lungs rather than gills. Lungs are pouches that extend into the body from external openings in the nose and mouth. As in the case of the trachea of insects, they are not exposed to wind, and therefore the amount of water lost through them is kept to a minimum. The surface of a human lung is not smooth, but consists of numerous blind pouches called alveoli. Capillaries of the circulatory system lie adjacent to the epithelium of the alveoli, and they absorb oxygen from the air of the alveoli and release carbon dioxide to it. The respiratory surface of the two lungs of a human being is about 50 times that of his skin.

THE STATE OF GASES IN THE BLOOD

Oxygen is soluble in water, and therefore it can dissolve in plasma, the liquid portion of the blood. However, oxygen is not so highly soluble in water that the circulating plasma can bring to the cells of the human body all they require. The red blood cells are rich in the pigment hemoglobin, which under certain circumstances has a great affinity for oxygen. Because of this, blood with its red blood cells can carry much more oxygen than can the plasma alone. About 98 percent of the oxygen in the blood is carried by hemoglobin, and only 2 percent is present in the plasma.

Hemoglobin has a purplish color. When it combines with oxygen, it forms oxyhemoglobin, which has a bright red color. The reaction, which is reversible, usually is written

$$Hb + O_2 \rightleftarrows HbO_2.$$

One molecule of hemoglobin, however, consists of four heme molecules combined with a protein (globin). Each heme portion is capable of combining with one molecule of oxygen, and therefore one hemoglobin molecule may carry up to four oxygen molecules. The number depends on several conditions, including the concentration of oxygen and the pH reaction of the blood.

Where the oxygen concentration is high, as it is in the lungs, hemoglobin tends to unite with oxygen. Where the oxygen concentration is low, as it is in tissues that utilize it in chemical respiration, hemoglobin tends to release oxygen. This characteristic, of course, makes it an excellent transporter of blood in the body, for it accepts oxygen in the lungs and releases it where needed.

At sea level, a barometer measures atmospheric pressure as 760 mm of Hg (mercury). Because oxygen accounts for only about ⅕ of the gases in the air, its tension (pressure) is about 150 mm of Hg. In the alveoli of the lungs, the concentration drops somewhat, and its tension is 105 mm. In the arteries that conduct blood to the tissues of the body, its tension is only slightly less—100 mm.

At oxygen tensions of 80 mm or higher, hemoglobin usually is 90 percent saturated or more; that is, the hemoglobin in the blood is carrying at least 90 percent of the oxygen it would if every molecule were transporting four oxygen molecules. In actively respiring tissue cells, however, the tension of oxygen rarely exceeds 40 mm, and it may be as low as 0 mm. Under such conditions, the hemoglobin releases much of its oxygen. In the blood that returns to the lungs, the oxygen tension is about 40 mm. At such low oxygen tensions, the hemoglobin is carrying much less oxygen than it otherwise might, and as it passes through the capillaries of the lungs, it picks up more oxygen and becomes nearly saturated with it once again.

The more acid the blood, the less oxygen can hemoglobin hold. In actively respiring tissues, carbon dioxide is formed as a waste product. Some of it dissolves in the plasma, and it makes the blood more acid. Thus the production of carbon dioxide by tissues increases the amount of oxygen liberated to them. In the lungs, the carbon dioxide leaves the blood and is exhaled. This makes the blood here a little more alkaline and increases the amount of oxygen that the hemoglobin can pick up from the alveoli.

Only about 5 percent of the carbon dioxide in the blood is dissolved in the plasma. Most of it (about 85 percent) is transported as the bicarbonate ion (HCO_3^-), and about 10 percent combines with hemoglobin. The latter is released from the hemoglobin when it reaches the lungs.

REGULATION OF BREATHING

Breathing is immediately under the control of certain muscles—the diaphragm and the intercostal muscles (rib muscles). The contraction and relaxation of these muscles in turn is controlled by nervous centers in the brain.

The lungs lie within the thoracic cavity of the chest. This cavity is surrounded by the rib cage, and it is separated from the abdominal cavity by the diaphragm, a large, dome-shaped muscle. An inspiration is caused by the contraction of the intercostal muscles and the diaphragm. As the intercostal muscles contract, they raise the rib cage slightly and move the ribs slightly forward. As the diaphragm contracts, it moves downward. Both of these actions increase the size of the thoracic cavity. This reduces the air pressure inside the lungs and causes air to move into them. When the muscles relax, the ribs are lowered and move inward, and the diaphragm bulges upward. These actions decrease the size of the thoracic cavity and force air outward in an expiration.

The nervous control of the intercostal muscles and the diaphragm is complex. In part it involves a respiratory center in the medulla oblongata and the pneumotaxic center in the pons. The respiratory center is divided into two portions—the inspiratory center and the expiratory center.

Nerve impulses sent along motor neurons from the inspiratory center to the intercostal muscles and the diaphragm cause them to contract, and this brings about an inspiration. Sensory neurons with dendrites in the lungs transmit information to the expiratory center when the lungs have stretched from inspiration. This causes the expiratory center to send inhibitory impulses to the inspiratory center, which then stops sending impulses to the muscles. As the muscles relax, an expiration occurs. As the lungs become deflated, they no longer stimulate the sensory nerves to the expiratory center, which, in turn, stops sending its inhibitory impulses to the inspiratory center. This completes one cycle of inspiration and expiration. Freed from inhibition, the inspiratory center transmits new impulses to the muscles to contract and begin another cycle. Ordinarily this cycle is repeated automatically throughout the life of an individual without the necessity of his thinking about it.

Some of the impulses traveling from the inspiratory center to the expiratory center go by way of the pneumotaxic center.

The rate of breathing and its depth is controlled largely by the amount of carbon dioxide in the blood, rather than the amount of oxygen. As carbon dioxide accumulates, the breathing becomes faster and deeper. Sense receptors in the aorta and in the carotid sinuses, small swellings in the carotid arteries, are especially sensitive to changes in the carbon dioxide content of the blood. They send nerve impulses that stimulate the respiratory and pneumotaxic centers when the concentration of this gas becomes high.

THE PHYSIOLOGY OF THE NERVOUS SYSTEM

One of the characteristics of living matter is the ability to respond to stimuli. This attribute is called irritability, sensitivity, or excitability. A stimulus is any change in the environment that produces a response. If the response is increased activity, the protoplasm is said to be excited; if the response is decreased activity, the protoplasm is said to be inhibited. Although the nervous system is immediately thought of when irritability is mentioned, all protoplasm is excitable in varying degrees, whether or not a nervous system is present. A one-celled amoeba extending its pseudopodia to engulf food is irritable, and a seedling bending toward the light is irritable. Whether it is man or amoeba, excitation includes the reception of a stimulus, the transmission of that stimulus, and the response to that stimulus. The nature of the response in man varies depending on where the transmitting nerve ends. If it ends in muscle fibers, the muscle will contract; if it ends in a gland, the cells of that gland will secrete.

CHARACTERISTICS OF THE NERVE IMPULSE

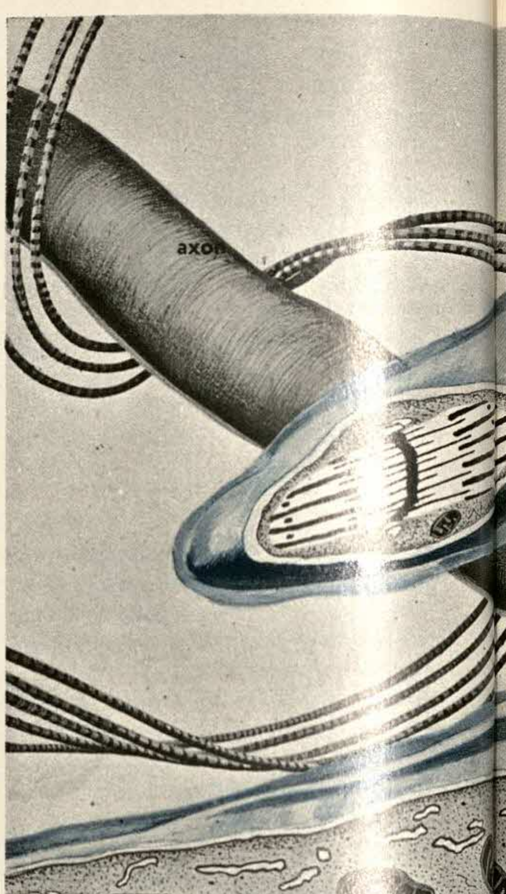
The characteristics of the nerve impulse are the same in all animals that have a nervous system. The nature of the response, however, may differ. It becomes increasingly complex in the more highly evolved animals as the number of interconnections between receptors and brain becomes more intricate. Although all protoplasm is irritable, the nervous and muscular systems have this characteristic to an outstanding degree.

A change in the environment may not necessarily be a stimulus because it may not be strong enough to bring about the chemical and physical changes in the receptor cell that would lead to the formation of a nerve impulse. Furthermore, nerve cells may become adjusted to gradual and uniform changes so that a change in the environment, if slow and uniformly applied, may not act as a stimulus. This principle is known as accommodation. But sufficient speed and sufficient intensity are necessary characteristics of a stimulus. Both these factors can be determined precisely by using electrical stimuli and recording devices. From such experiments, usually conducted on a nerve-muscle preparation, a number of principles have been determined. A nerve-muscle preparation consists of an excised nerve still attached to the muscle it supplies, so that as the nerve is stimulated the response in the muscle may be observed and measured. Among the important characteristics observed in this manner are the following:

1. There must be an adequate stimulus in order to have a response take place. The term rheobase is used to describe the minimum current needed to excite a nerve. Any stimulus under this minimum is subliminal (too weak) to produce a detectable response.

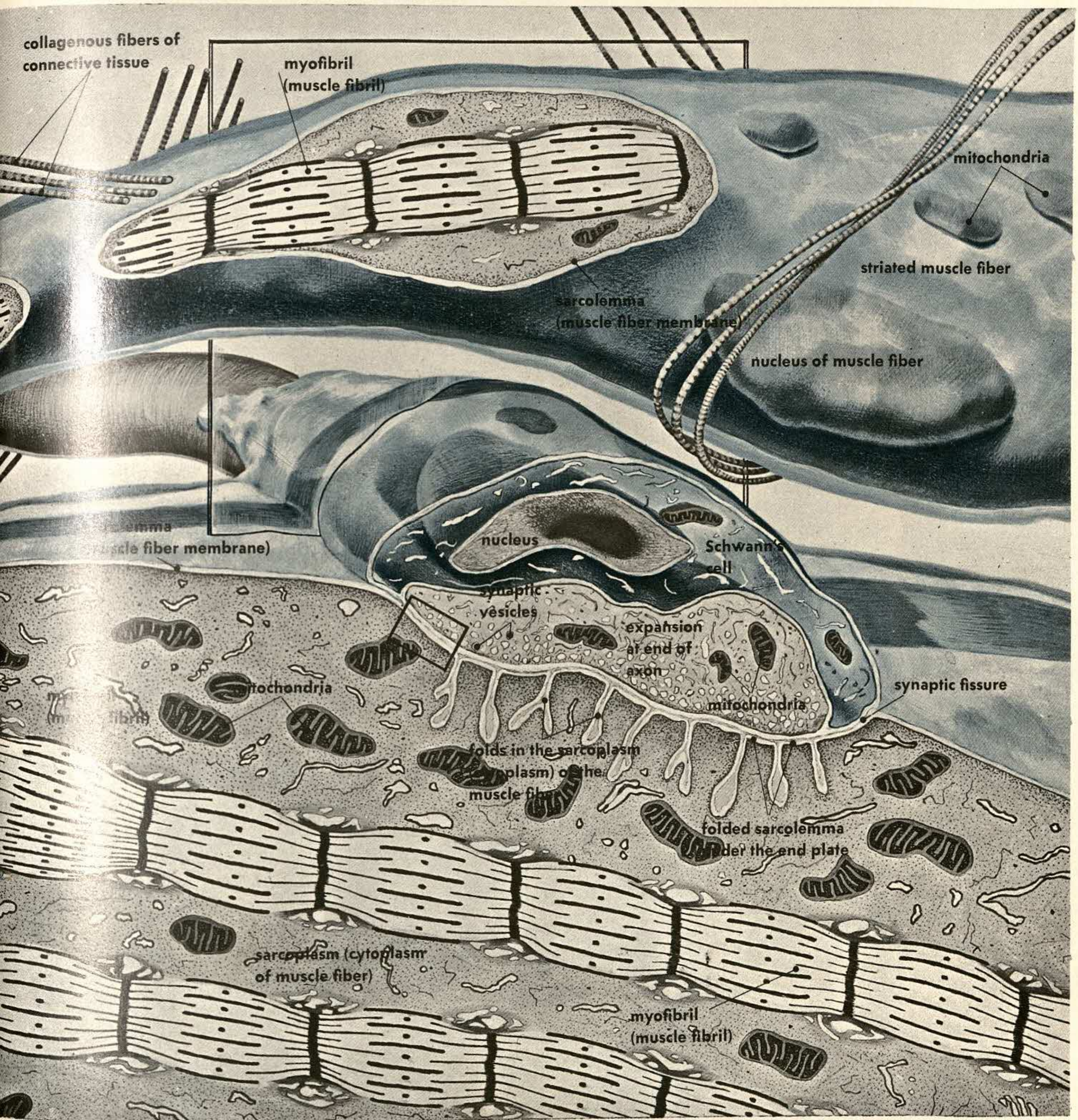
2. If a number of subliminal stimuli are applied very close together, they have a reinforcement effect. This reinforcement is known as the summation of subliminal stimuli. The nerve will respond to a rapid series of subliminal stimuli, any one of which alone would not produce an effect.

3. However, if a second stimulus is sent within a very short time, about 0.4 milliseconds, after the first one, there is no response. The time during which irritability is completely lost is called the absolute refractory period. As irritability is regained, there is a period, called the relative refractory period, during which a stimulus of more than normal minimal strength is required to produce an impulse. The refractory periods are explained by the nature of the nerve impulse. When a fiber is at rest with no impulse traveling along its length, the fiber is polarized, with positive sodium ions lined up on the outside of the fiber and negative ions such as chlorine on the inside of the fiber. A stimulus increases the permeability of the membrane, allowing the positive ions on the outside to travel to the inside, thus reducing its internal negativity. The fiber is thus depolarized for a short distance near the point of stimulation. Depolarization at this point induces depolarization farther along the fiber. This wave of depolarization constitutes the nerve impulse. Since a measurable amount of time is required to repolarize after the impulse has passed, there is a short time (the refractory period) when a nerve cannot carry an impulse; hence, no response to a stimulus is possible.



A MOTOR END PLATE—This illustration, drawn from an electron microscope photograph, shows a neuromuscular junction. The

4. Not only must a stimulus be of at least minimal intensity, it must also act for a certain length of time to produce a response. Within limits, the stronger the stimulus, the shorter the time needed for its application. This can be expressed as $a = i \times t$, where $a =$ the response, $i =$ the intensity of the stimulus, and $t =$ the duration of the stimulus. Because the exact minimum of intensity (rheobase) is difficult to determine because of the accom-


collagenous fibers of connective tissue
myofibril (muscle fibril)
mitochondria
striated muscle fiber
sarcolemma (muscle fiber membrane)
nucleus of muscle fiber
emma
scle fiber membrane)
nucleus
Schwann's cell
synaptic vesicles
expansion at end of axon
mitochondria
mitochondria
synaptic fissure
folds in the sarcoplasm (cytoplasm) of the muscle fiber
folded sarcolemma under the end plate
sarcoplasm (cytoplasm of muscle fiber)
myofibril (muscle fibril)

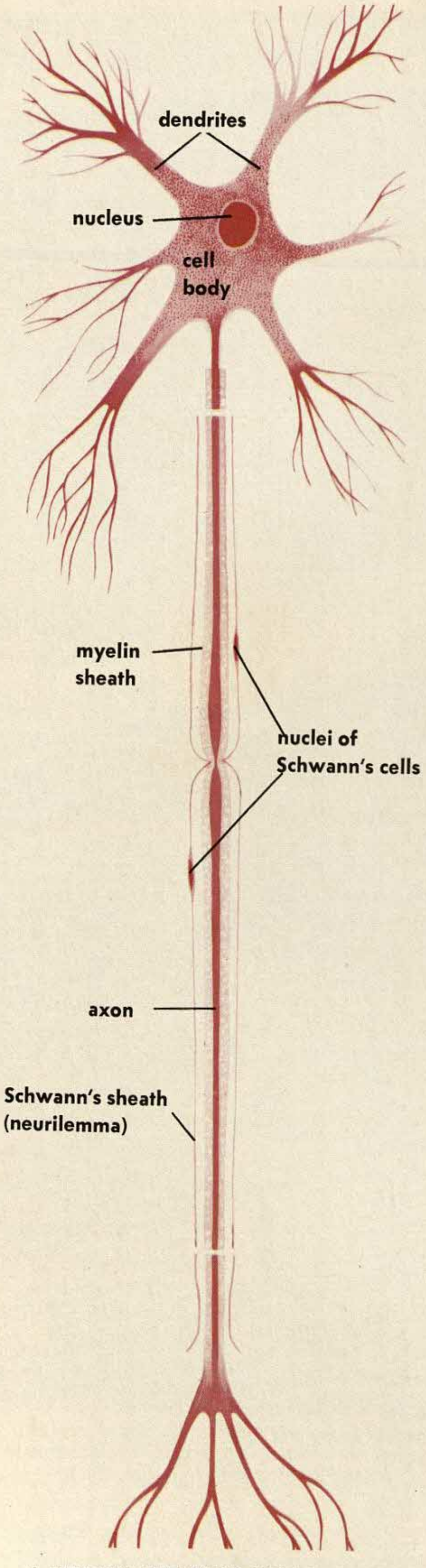
expanded end (motor end plate) of an axon is shown lying against a muscle. At this point the impulse is transmitted from the neuron to the muscle, thus causing the contraction of the muscle. The motor end plate contains synaptic vesicles like those found in the endings of axons at a synapse, the tiny space between two neurons in a chain of neurons that are formed by nerve cells in higher animals.

modation principle, a value that represents intensity and duration is commonly used in describing the excitability of a tissue: chronaxy. It is the time needed by a current whose intensity is twice that of the rheobase to bring about a response. While rheobase expresses excitability in relation to the intensity of the current, chronaxy relates excitability to both intensity and time.

CHRONAXY OF VARIOUS NERVES AND MUSCLES
(in milliseconds)

sciatic nerve of frog	0.3
gastrocnemius muscle of frog	0.3
ventricle of frog heart	3.0
ventricle of dog heart	2.0
neuron of earthworm ganglia	100.0
flexor muscle of human arm	0.08

5. Nerve fibers, like muscle fibers, either respond or do not respond. In both cases this phenomenon is called the all-or-none law; it is sometimes hard to demonstrate because nerves and muscles are both composed of numerous fibers (axons, dendrites, or muscle cells), so that when the tissues are stimulated, many individual fibers are excited. The number of excited tissues depends on the



A NEURON: THE BASIC UNIT OF THE NERVOUS SYSTEM—The nervous system is composed of nerve cells (neurons) with short, branching processes or fibers (dendrites) and a long process (axon) that does not branch until near its end. Dendrites receive stimuli and pass the impulse to the cell body. From there the impulse travels to the axon, which carries it away from the cell body. Most axons are covered with a myelin sheath and a neurilemma (sheath of Schwann).

intensity and duration of the stimulus. If at one time a nerve seems to respond more vigorously than at another time, it may not mean a difference in the nature or strength of the impulse traveling along a fiber, but merely a difference in the number of fibers responding.

NEURONS

While irritability is one of the characteristics of all living cells, nerve cells (neurons) have it to an extraordinary degree. The structure of the neuron is adapted to this function. It has a cell body with a nucleus, similar to all cells, and a number of long extensions or processes from the cell body. Usually, although not always, there are a number of rather short, much branched extensions (processes or fibers) called dendrites, which bring the nerve impulse into the cell body, and one axon, which carries the impulse away from the cell body. Axons are usually long, smooth, and straight, with few branches until the terminal arborization is reached. Nerves are made up of bundles of neuron processes—axons, dendrites, or both.

Neurons may be classified in various ways. One method of classification depends on whether or not a myelin sheath encloses the axons—although recent studies using the electron microscope and very high powers of magnification make the distinction less clear than was formerly thought. Unmyelinated nerve fibers have a very thin sheath or neurilemma around the axon made of the expanded cytoplasm of Schwann's cells. Myelinated fibers, which are much more common, have a layer of myelin wrapped around the axons. Myelin occurs in segments with small gaps between the segments. Chemically, myelin is a lipoid or lipoprotein. The neurilemma (sheath of Schwann) is outside the myelin and dips down between the myelin segments to touch the axon cylinder at the nodes of Ranvier. A factor that influences the speed of the impulse is the diameter of the fiber. The greater the diameter, the faster the impulse travels. Myelinated fibers, even without their covering of myelin, are usually greater in diameter than unmyelinated fibers.

Another way in which neurons may be classified depends on whether they are sensory or motor in function. Sensory (afferent) neurons and nerves carry impulses from sense receptors toward the central nervous system (brain and spinal cord). Motor (efferent) neurons and nerves carry impulses away from the central nervous system to some effector organ such as a muscle or a gland. Still another way of classifying nerves is to separate them according to whether the impulses they carry cause excitation or inhibition of the tissue that they innervate. The different effects obtained by the stimulation of different nerves are due to the different organ or tissue to which the stimulus is sent, and not to the nature of the impulse itself. The impulse that travels along a neuron is always the same in chemical-physical properties.

THE SYNAPSE

The terminal branches of the dendrites may act as sense (stimuli) receptors, or they may lead away from a major sense organ such as the eye or ear. The terminal branches of the axons end in various effector organs such as muscles or glands. In higher animals, nerve cells form chains or relays of neurons, the end of the axon of one cell nearly touching the dendrites or cell body of the next neuron. The very minute space between two neurons of such a relay is the synapse. Some of the more puzzling aspects of nerve conduction have to do with what happens at the terminations of neurons and what happens at the synapses. An isolated nerve fiber, for example, does not become fatigued; it will transmit impulses repeatedly with no lessening of its strength or speed. It has been found, however, that when a nerve-muscle preparation is stimulated again and again, the muscle soon fails to contract. However, since neither nerve fibers nor muscle fibers become fatigued when stimulated independently, fatigue must be occurring at the junction between the two. At this neuromuscular junction the nerve endings are modified in various ways, usually by small expansions called motor end plates. Similarly, when fatigue appears in a relay of neurons it can be shown that it is occurring at the synapse rather than in the neurons themselves. Another characteristic of the neuron-synapse complex is that the impulse will travel in only one direction across the synapse—from the axon of one neuron to the dendrites of another neuron; whereas if an individual fiber is isolated and stimulated electrically at various points, the impulse will travel in either direction along the fiber.

In 1921 the German physiologist Otto Loewi showed that a substance, later identified as acetylcholine, is released by the stimulated vagus nerve where it terminates in the muscle of the heart. It is now known that most axons release acetylcholine and that acetylcholine is the transmitting agent, stimulating the dendrites of the next neuron, or transmitting the stimulus to a muscle at the neuromuscular junction.

THE CARBON AND NITROGEN CYCLES

the plant produces, the animal consumes

The process of photosynthesis usually brings to mind the absorption of carbon dioxide and the production of oxygen by plants. Less often is it remembered that, thanks to this process of photosynthesis, the vegetable kingdom not only maintains the concentrations of oxygen (about 20 percent) and of carbon dioxide (about 0.03 percent) at constant levels in the atmosphere, but it also synthesizes organic substances from inorganic ones by utilizing the radiant energy of the sun. The energy necessary for all metabolic and functional activities carried on by any animal is, in the final analysis, derived from organic compounds produced by plants, for animals are not capable of photosynthesis.

THE PRODUCT OF PHOTOSYNTHESIS

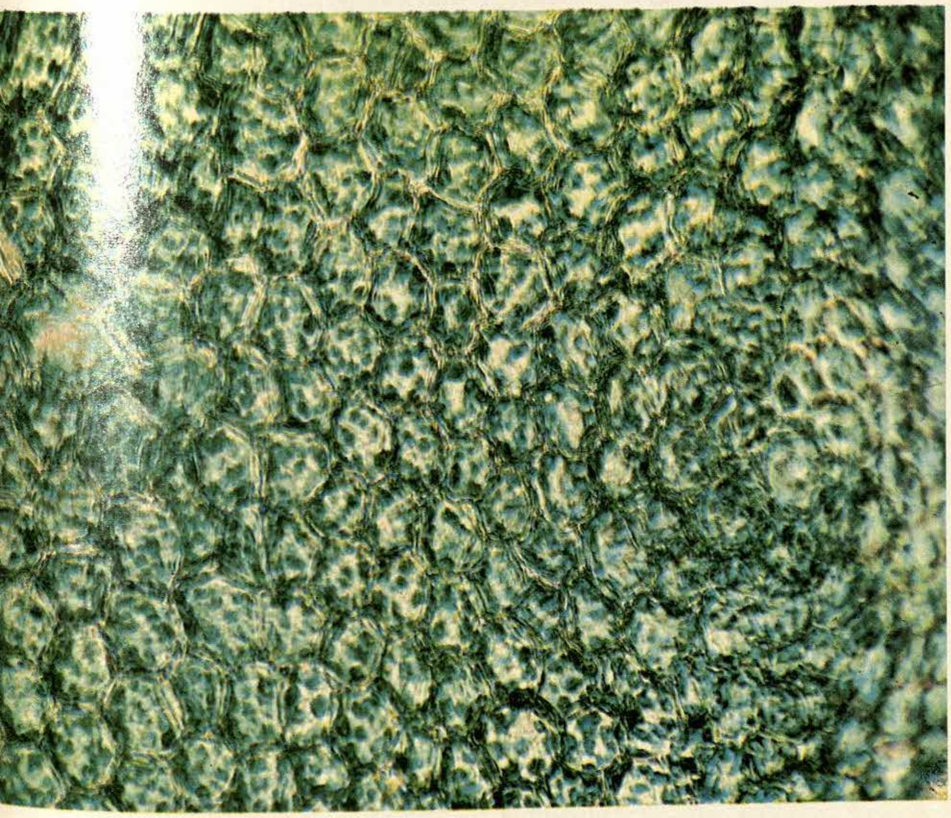
The primary product of photosynthesis is glucose, a simple sugar (monosaccharide); it is an organic compound that the plant manufactures from carbon dioxide and water. Glucose is synthesized in green portions of the plant where it may be converted into starch, a polysaccharide composed of long chains of connected glucose molecules. Such a chain may contain from 300 to 1,800 molecules; some of these starch chains are branched, while others are not. Starch is not soluble in water and therefore cannot become part of the sap that flows in the plant body, but it can be converted back to glucose or to other soluble sugars. Some of these glucose molecules are utilized in various metabolic processes where they are formed; others are transported in the sap to other parts of the plant where they are once again converted into starch and stored as reserve food material, or where they enter into other processes.

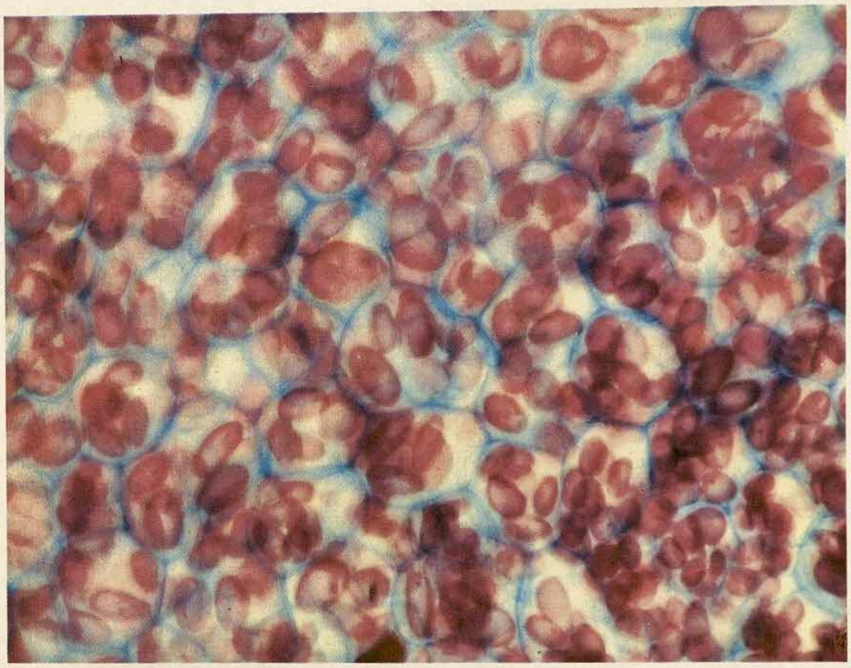
In plants there are two enzymes capable of digesting starch by breaking glucosidic bonds (bonds linking glucose molecules): alpha-amylase (also present in human tissue) and beta-amylase. Alpha-amylase can digest completely both branched and unbranched starch molecules; it acts by breaking them into smaller chains called dextrins, and then by digesting these to maltose (a disaccharide, or sugar composed of two glucose molecules linked together). Beta-amylase acts by sequentially removing maltose units beginning at one end of the starch molecule and proceeding to the other end. Since beta-amylase cannot proceed past a point of branching of the starch molecule, it can digest unbranched starch chains completely, but when acting on branched molecules it produces some maltose and dextrins. Both types of enzymes are known as hydrolases because they break glucosidic bonds by introducing a water molecule between two adjacent glucose molecules. Maltose can be further digested to glucose, which can then be utilized in any of several processes.

HOW SUGARS ARE USED BY PLANTS

Like animals, plants absorb oxygen from their surroundings. They utilize the oxygen in the oxidation of glucose or other organic compounds, which are thereby converted to carbon dioxide and water; this process, respiration, releases energy. The several steps in respiration are divided into two main groups: glycolysis and the Krebs cycle. The respiration of some glucose molecules provides the energy that permits other glucose mole-

CHLOROPLASTS—The chloroplasts, which are small bodies located in the cytoplasm, contain chlorophyll, the pigment necessary for a plant's synthesis of sugar from carbon dioxide and water. The concentration of chloroplasts varies in different cells, but they generally are more numerous in leaves than in other organs. In the unicellular algae, there may be only one or two large chloroplasts per cell.





STARCH GRAINS—As a result of photosynthesis, starch is deposited in leaves in the form of starch grains. The starch, which is composed of chains of linked glucose molecules, remains in the leaves only a short time and soon is digested into glucose. The glucose is transported to various organs of the plant where it may be transformed back into starch again or may be utilized in other processes. (260 X)

cules to be converted into other carbohydrates, lipids, or proteins—all essential constituents of every living cell.

Carbohydrates are the most common organic compounds in plants; they consist of the elements carbon, hydrogen, and oxygen, and include sugars, starch, and cellulose. The latter is an important constituent of plant cell walls.

Lipids include fats, oils, and related substances. Like carbohydrates, they are composed of carbon, hydrogen, and oxygen, but they have a higher energy value.

Proteins are composed primarily of carbon, hydrogen, oxygen, and nitrogen, and often include sulfur and mineral elements.

THE CARBON CYCLE

In the great cycles of nature, plants are the producers, and animals are the consumers. In eating plants, animals utilize the substances contained in them both as energy sources and as materials with which to build their own tissues. When plants and animals die, the carbon in their bodies is restored to the atmosphere by a third category of organisms—the bacteria. By their own respiration, bacteria decompose dead organisms and convert their organic carbon compounds to carbon dioxide, which plants can then use again in the process of photosynthesis. The carbon cycle is illustrated in the upper diagram in Illustration 3.

THE NITROGEN CYCLE

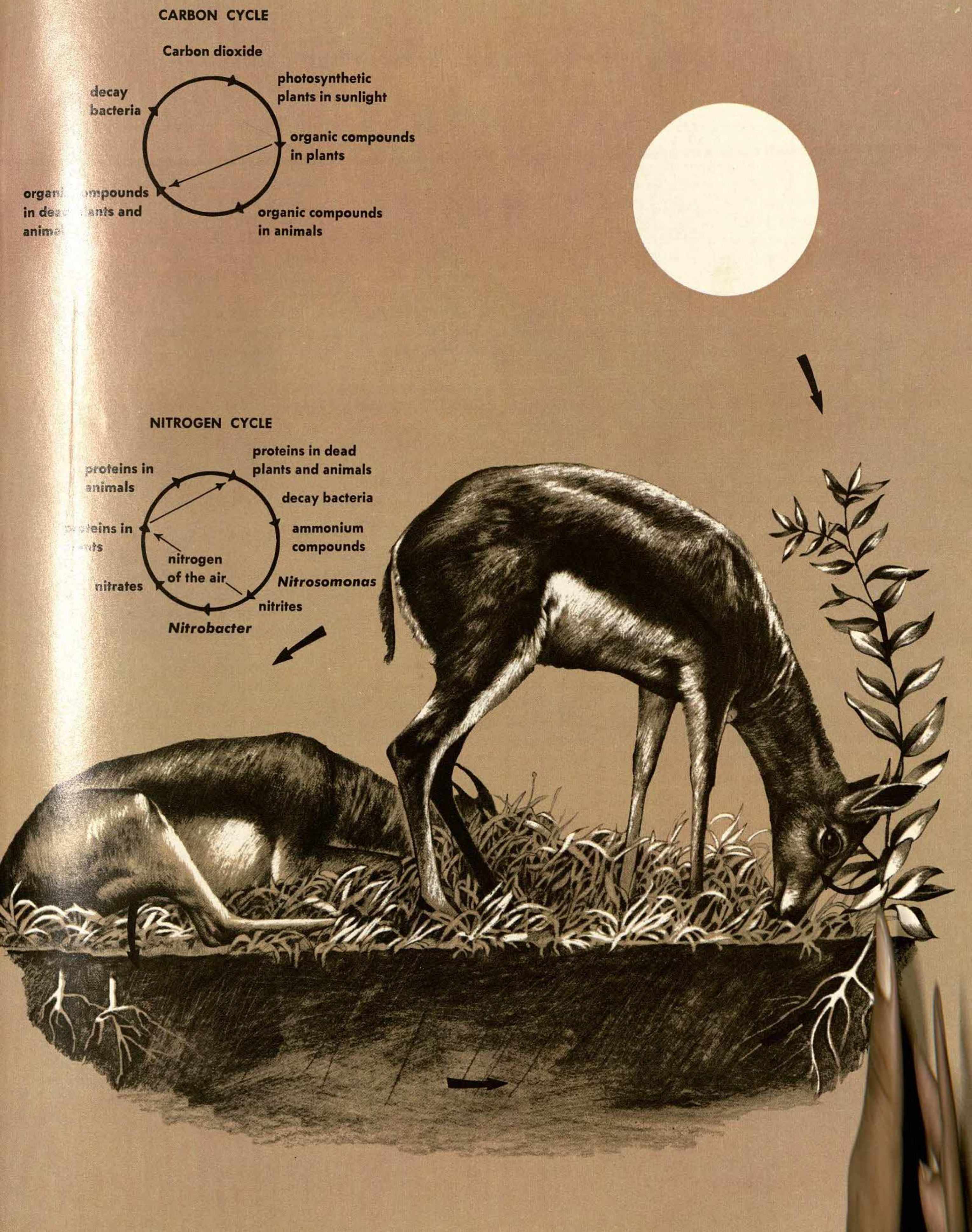
All living things need nitrogen, but the nitrogen that makes up about 80 percent of the atmosphere cannot be utilized directly by animals or by most plants. Most plants obtain their nitrogen from nitrogenous compounds in the soil. Experiments have shown that plants cultivated in nutritional solutions lacking nitrogen but exposed to the nitrogen of the air soon reduce their photosynthetic activity and cease to grow. Such experiments demonstrate that most plants are incapable of utilizing the nitrogen of the atmosphere. Exceptions to this general rule are the legumes (members of the bean and pea family), which live in symbiotic relationship with nitrogen-fixing bacteria. In fact, when leguminous plants with their symbiotic bacteria are cultivated in soil that is completely lacking in nitrogen compounds, they enrich the soil with this element, thus improving its agricultural potential. Other plants, however, are able to utilize only the nitrogen contained in the soil in the form of ammonium (NH_4^+) or nitrate (NO_3^-) compounds, the latter being the more readily used.

Regardless of the form of nitrogen that they use, plants convert it into the amino form ($-NH_2$) in their proteins. Upon the death of plants and animals (which get their protein by eating plants), the protein is decomposed by decay bacteria, and the nitrogen is released into the soil in the form of ammonium ions.

Soil bacteria of the genus *Nitrosomonas* oxidize the ammonium ion to the nitrite ion (NO_2^-), which is further oxidized by bacteria of the genus *Nitrobacter* into the nitrate ion (NO_3^-) that is then utilized by plants. The nitrogen cycle is presented in the lower diagram of Illustration 3.

The carbon and nitrogen cycles are the two principal cycles in nature, but there are also other cycles, such as those of sulfur and phosphorus. The continuous transformation of matter from an organic form to an inorganic form (and vice versa) and the continuous passage of matter between living things and their environment constitute cycles.

THE CARBON AND NITROGEN CYCLES—Utilizing the energy in sunlight, plants convert carbon dioxide into organic compounds. Grazing animals eat plants and thereby incorporate these compounds into their bodies. The decomposition of dead organisms by soil bacteria converts these organic compounds into inorganic matter, which is used again by plants. →



CARBON CYCLE

Carbon dioxide
photosynthetic plants in sunlight
organic compounds in plants
organic compounds in animals
organic compounds in dead plants and animals
decay bacteria

NITROGEN CYCLE

proteins in dead plants and animals
decay bacteria
ammonium compounds
Nitrosomonas
nitrites
Nitrobacter
nitrates
proteins in plants
proteins in animals
nitrogen of the air

VIRAL INFECTION | the pathogenic action of viruses

The viruses—so small that most are invisible even under the highest magnifications of the light microscope—could not be satisfactorily examined until the invention of the electron microscope. Their presence was suspected long before this, however, for many of them cause diseases of human beings, domestic plants, and animals.

Viruses are unusual in having no cellular structure. Because of this, some biologists prefer to consider them as nonliving; however, viruses do have some features of living organisms, including the powers of reproduction and mutation. Their chemical composition resembles that of the genetic material of cellular organisms.

A virus particle consists of a central core of nucleic acid surrounded by a layer of protein called a capsid. The nucleic acid is either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA), but a given virus never contains both. This is another way in which viruses differ from cellular organisms, for the latter contain both DNA and RNA within a cell. The protein capsid consists of several repeating subunits called capsomeres. In addition to nucleic acid and protein, carbohydrates and lipids are found in some viruses.

If properly treated, virus particles can be crystallized and stored in a bottle like any ordinary laboratory chemical. In this condition they exhibit no metabolic activity and seem not to be living. They do retain their powers of infection, however, and can cause the symptoms of disease if they are introduced into a suitable host plant or animal.

All viruses are obligate parasites, a fact that is not surprising in view of their structure, for they have no cytoplasm in which to synthesize their own enzymes. Enzymes, essential for life, are proteins that are synthesized on the ribosomes in the cytoplasm of cells. When viruses invade living cells, they utilize the cellular machinery that is already present in the host cell. Under the direction of the viral DNA or RNA, proteins peculiar to the particular virus may be synthesized in the host cell cytoplasm. When this happens, the host cell is damaged. If the damage is severe enough, disease results, and sometimes death.

VIRAL DISEASES

Viral diseases of humans range from annoyances such as cold sores and the common cold to such serious diseases as poliomyelitis, smallpox, rabies, and yellow fever. Among the so-called children's diseases are chicken pox, measles, German measles, and mumps. Influenza is also a virus-caused disease. Warts are caused by viruses, and ever-increasing evidence indicates that viruses are responsible for at least some cancers.

Some viruses are transmitted by direct contact with infected persons or with bedclothing, handkerchiefs, or other articles they may have handled. Smallpox, chicken pox, measles, German measles, mumps, and influenza may be contracted in this way. Droplet infection—transmission by sneezing or coughing small droplets of moisture containing virus particles into the air—is responsible for the spread of measles, German measles, and influenza. Poliomyelitis virus is spread in food and water. Rabies is ordinarily contracted only from the bite of a rabid animal; the rabies virus is present in the saliva of the animal. If the bite punctures the skin, the viruses may reach the nervous tissue; they infect primarily the spinal cord and brain. Yellow fever is spread by the bites of mosquitoes, especially *Aëdes aegypti.* Cancers have such a low degree of infectivity as to be essentially noncontagious.

IMMUNITY TO VIRAL INFECTIONS

The introduction of a foreign protein, such as the virus capsid, into the human body usually triggers the production of antibodies. Antibodies are proteins, and by a variety of mechanisms they neutralize the effects of the foreign protein or antigen. Antibodies are highly specific; they protect the body only against the type of organism that initiated their formation. The antibodies specific for measles, for example, do not protect against yellow fever. The initial production of antibodies is relatively slow, and they usually do not protect the patient against a first infection with that organism; they do, however, protect against any further infection by that organism. An attack of measles usually confers immunity to any subsequent infection by the measles virus.

Both bacteria and viruses cause the production of antibodies in the blood. Viruses also cause the production of interferon, a substance that aids in the control of an initial infection. Interferon is not so specific as antibodies; produced in response to the introduction of one virus into the body, it may also protect against other kinds of viruses. Interferon was named for its property of interfering with the multiplication of viruses.

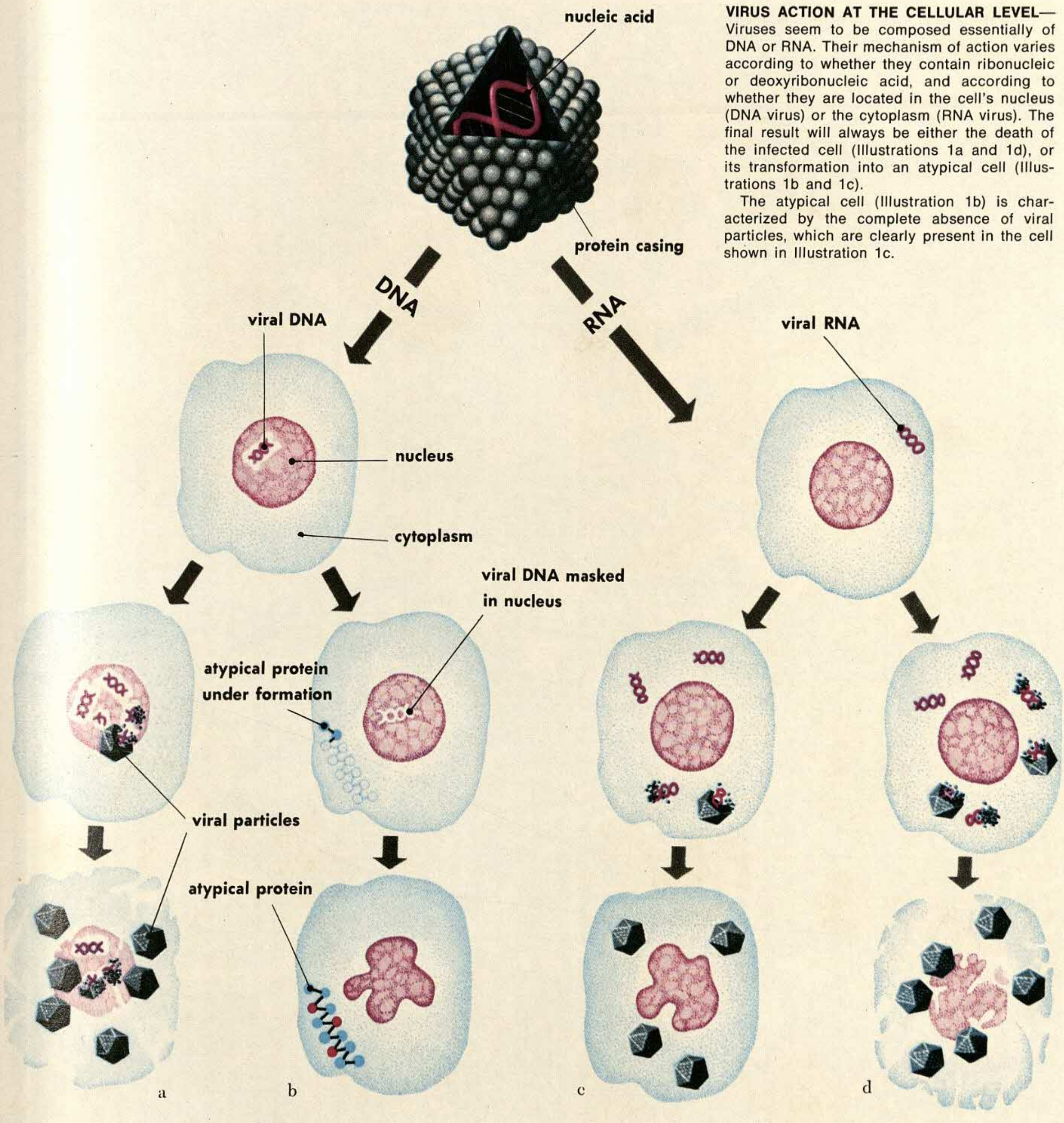
BACTERIOPHAGES

No major group of organisms is immune to attack by viruses. Even unicellular organisms are parasitized by them. One special group of viruses, the bacteriophages, attack bacteria. These viruses have been studied extensively because it is possible to obtain many generations of both bacteria and bacteriophages in a single day. Some experiments with these organisms can be performed in less than an hour.

A bacteriophage, or simply phage, consists of a polygonal protein head with a hollow tail; the head contains the DNA. When the phage attaches itself by its tail to the cell wall of a bacterium, a small hole is digested in the cell wall; the DNA of the head is then injected through the tail and into the bacterial cell. Once the nucleic acid has entered the cell, either of two things may happen: the phage may reproduce itself, or it may become incorporated into the bacterial chromosome.

Phage reproduction requires only about 30 minutes under suitable conditions. The phage DNA controls the synthesis of more phage DNA—identical copies of itself—and of the protein coats. The DNA particles and the protein coats

1



VIRUS ACTION AT THE CELLULAR LEVEL—Viruses seem to be composed essentially of DNA or RNA. Their mechanism of action varies according to whether they contain ribonucleic or deoxyribonucleic acid, and according to whether they are located in the cell's nucleus (DNA virus) or the cytoplasm (RNA virus). The final result will always be either the death of the infected cell (Illustrations 1a and 1d), or its transformation into an atypical cell (Illustrations 1b and 1c).

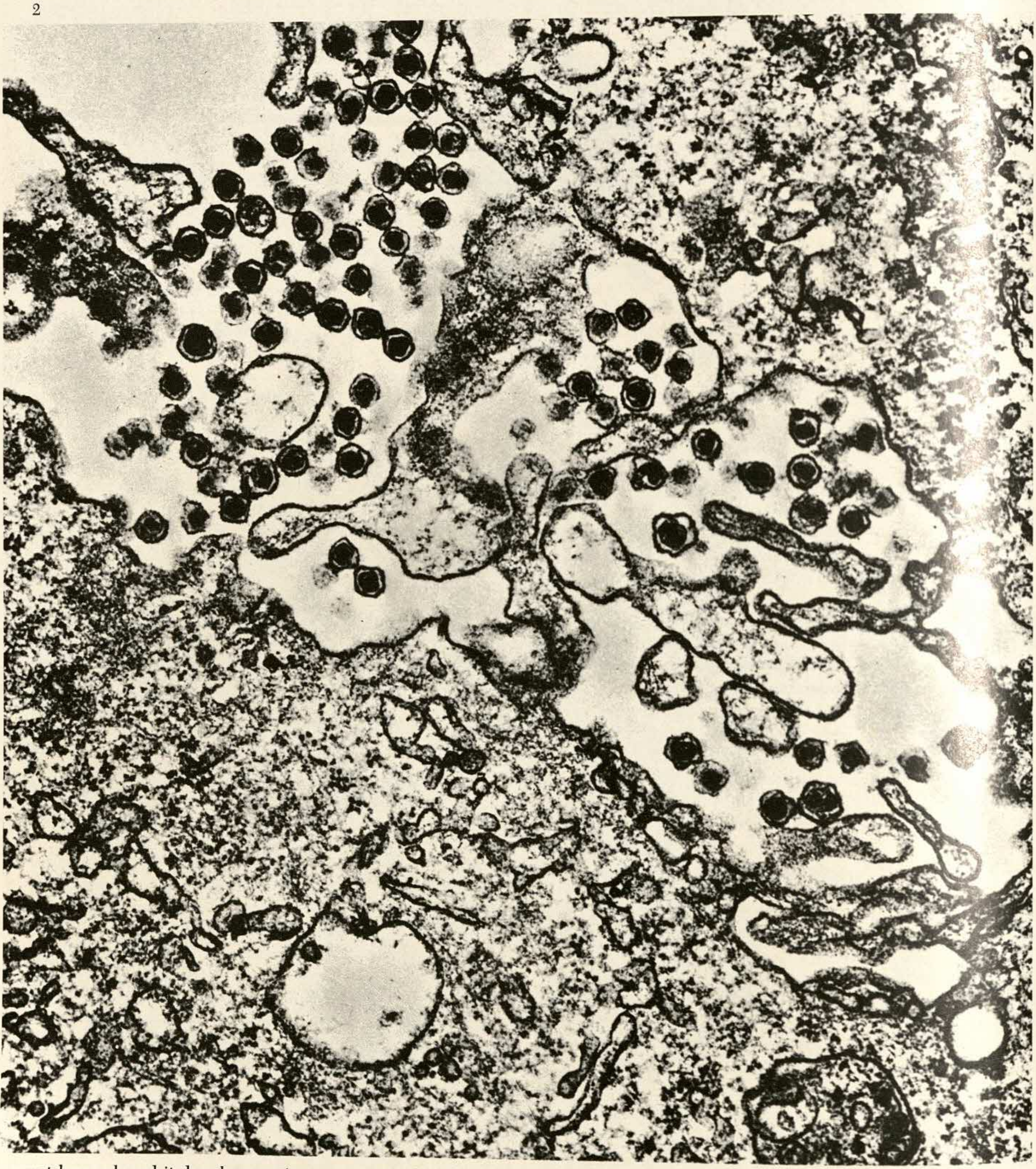
The atypical cell (Illustration 1b) is characterized by the complete absence of viral particles, which are clearly present in the cell shown in Illustration 1c.

then assemble into complete phage units; as many as 200 may be produced in a single bacterial cell. The cell wall breaks open and releases the new phage particles, each of which then is capable of infecting a new bacterial cell. The production of new phages causes the host cell to disintegrate or lyse. This cycle is called the lytic cycle.

If the phage DNA becomes incorporated into the bacterial chromosome, this phage DNA is called prophage, and the bacterium it infects is said to be lysogenic. In many cases there is almost no discernible effect on the bacterium; it is

VIRAL CULTURE—This electron micrograph shows cells infected with the B/T-L virus of rat leukemia. The viral particles, which can be identified in the space between the cells, have an outer capsid and a denser interior.

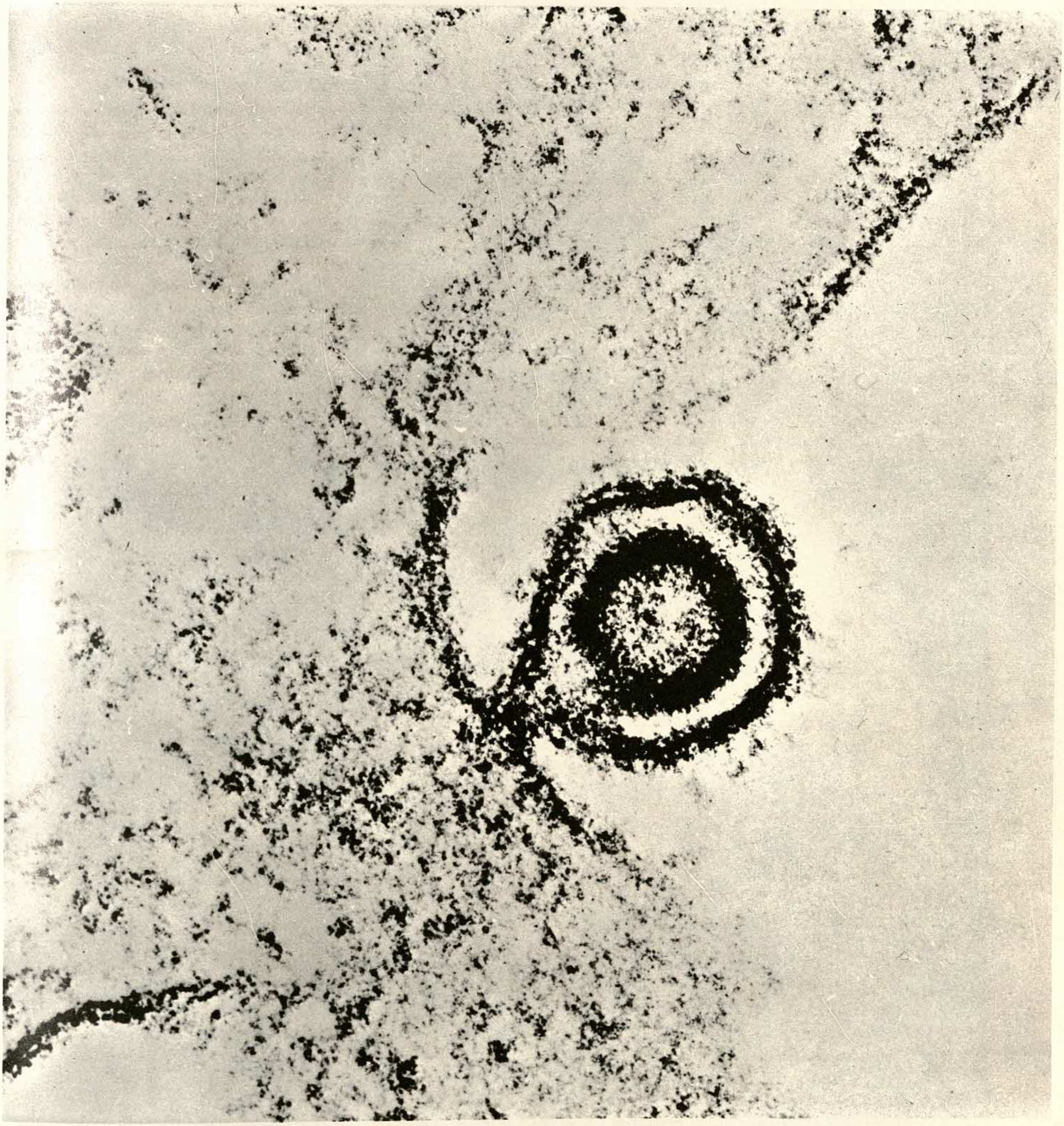
2



not harmed, and it does become immune to the entrance of more phage particles of the same type.

When a bacterial cell divides into two cells, its chromosome is duplicated also, one daughter chromosome going into one daughter cell and one into the other. Any prophage on the chromosome is duplicated as well, and both daughter cells receive the prophage. Because bacterial cells are not destroyed by this process, the lysogenic cycle may be repeated indefinitely without any further infection by phages, whereas each turn of the lytic cycle requires reinfection.

VIRUS B/T-L — This high-resolution electron micrograph shows the B/T-L virus of rat leukemia. The virus is in a reproductive phase during which the viral particle is located inside a bulge in the surface of the cell.



A variety of chemical and physical agents convert a prophage into lytic phage. Some of these agents include x-rays, ultraviolet light, and several cancer-inducing chemicals.

Because they can be conveniently propagated and observed in the laboratory, the phages have been studied extensively. Many different strains have been identified. In most cases, one kind of phage can attack only one or a very few closely related kinds of bacteria.

Antibiotics and synthetic chemicals that can kill bacteria have little or no effect on the phages and other viruses.

PATHOGENIC MICROORGANISMS

the cause of many diseases

The most dangerous organisms to human beings are not necessarily the large ones like elephants or lions. During his lifetime, nearly everyone becomes ill with diseases caused by microorganisms —bacteria, viruses, protozoa, or fungi. Those organisms that cause disease are called pathogens. Most of them are so small that they cannot be seen with the naked eye, and they can be taken into the body in food, water, or air that looks clean and pure.

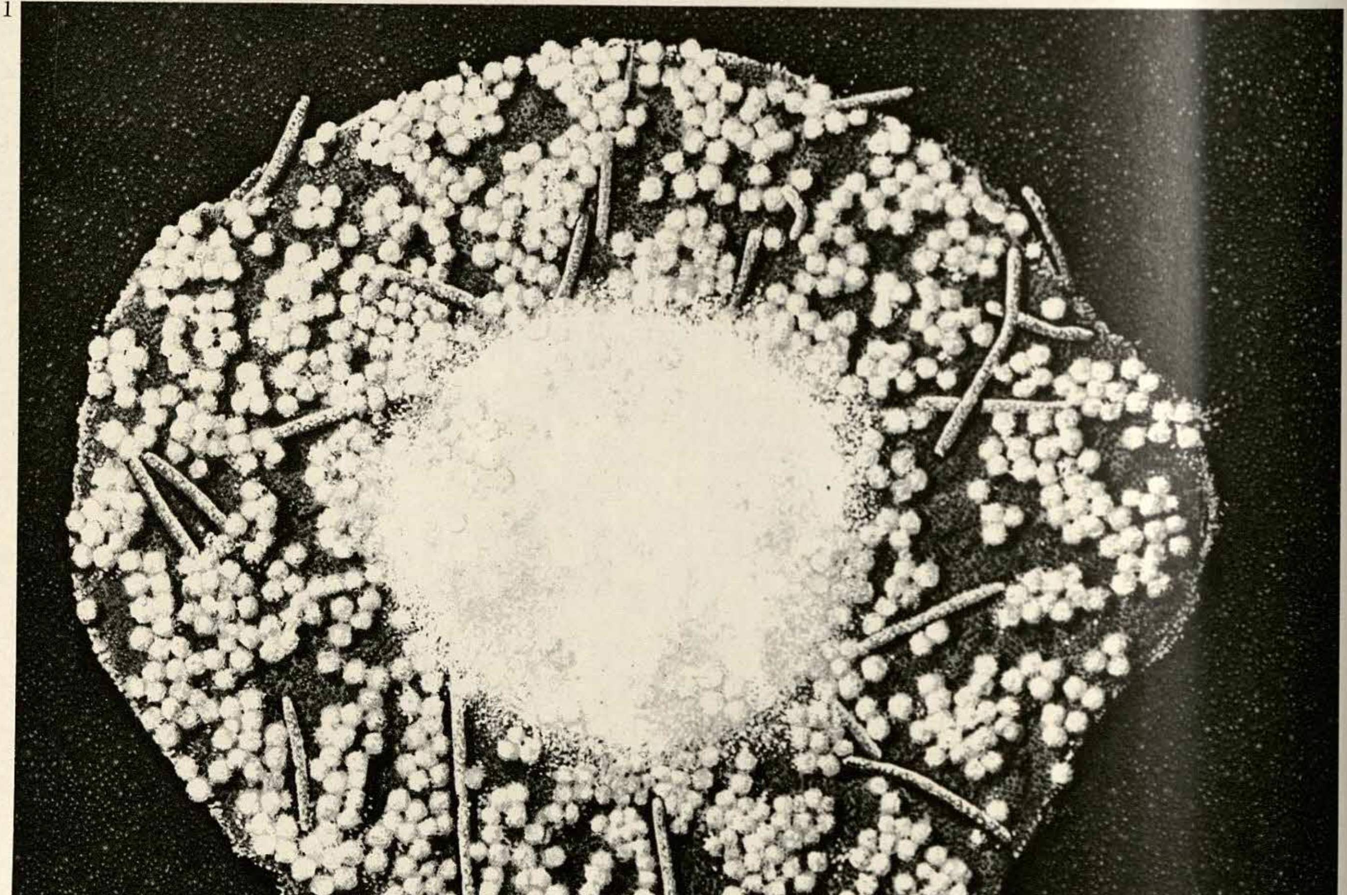
A single microorganism is so minute that by itself it can do little damage to its host; but most microorganisms have such rapid rates of reproduction that under favorable conditions, a single microorganism may have millions of descendants within 24 hours. In the warm, moist tissues of the human body, many pathogenic microorganisms find optimum conditions for growth and reproduction. Within a few days of infection, the number of pathogens within the body can reach astronomical numbers.

PORTALS OF ENTRY

Pathogens cannot cause disease unless they or the toxins they produce enter the body of a susceptible host. The point at which the entry is made is called the portal of entry. Many dis-

INFLUENZA VIRUS—This electron micrograph shows a red corpuscle of a chicken. The cytoplasm has been invaded by the influenza virus that appears in both transverse and longitudinal sections. The large white part is the nucleus of the corpuscle.

1



eases have more or less specific portals of entry. Organisms that cause respiratory diseases usually are coughed, sneezed, or exhaled into the air in minute droplets of moisture that remain suspended in the air for long periods of time and thus are likely to be inhaled by another person. Such infection is called droplet infection. Diseases transmitted in this way include tuberculosis, diphtheria, pneumonia, and the common cold.

The organisms of intestinal diseases are discharged from the body in fecal material which often reaches water supplies; in some parts of the world feces are used as fertilizer for crop plants. Any of these organisms that are ingested in untreated water or in raw foods (usually only those foods that grow under or near the ground) soon reach the intestine where they can set up an infection again. Among the food- and water-borne diseases are typhoid fever, paratyphoid fever, cholera, and amoebic dysentery.

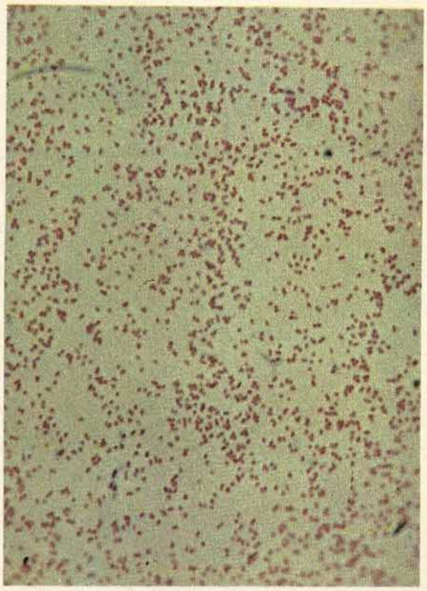
Malaria and some other diseases of the circulatory system are transmitted only by insect bites; in many cases only one species of insect is capable of transmitting the pathogen.

Such venereal diseases as syphilis and gonorrhea ordinarily are transmitted only by sexual contact.

Some diseases have only one effective portal of entry. The tetanus organisms cause disease, for example, only if they are introduced into a wound into which oxygen does not penetrate. Because the tetanus organism is common in the soil, it has been ingested by many people who have eaten raw root crops; but when the organism enters the body by way of the digestive system, it is harmless. Some diseases have more than one effective portal of entry. Scarlet fever and tuberculosis may be transmitted by contaminated milk or by droplet infection.

Some diseases with two portals of entry exhibit different effects, depending on the portal utilized. Bubonic plague is transmitted from rats to humans by the bites of rat fleas. The plague organisms usually are confined to the circulatory system, where they form large swellings called buboes. If the organisms should break out of the buboes and reach the lungs, they set up a different disease called pneumatic plague. This form of the disease can be transmitted from human to human by droplet infection without the help of fleas. The gonorrhea organism can be transmitted from a mother to her baby during birth. If the organism reaches the eyes of the infant, it can cause a form of blindness called gonorrheal ophthalmia.

2



PASTEURELLA PESTIS — This bacterium causes both the bubonic and pneumonic forms of plague. The organism secretes an exotoxin that inhibits aerobic respiration in the mitochondria. Strains of *P. pestis* from all over the world are biologically identical.

3

CLOSTRIDIUM BOTULINUM—This anaerobic bacterium grows in neutral, improperly canned food. It produces a powerful exotoxin that accumulates in the food. When ingested, the toxin interferes with nerve functions and causes paralysis.

VIRULENCE

The introduction of a pathogen into a host does not ensure that disease will result. The occurrence of disease depends on the virulence of the organism—its ability to spread throughout the body of the host or certain tissues and its ability to produce toxins or to do other damage to the host.

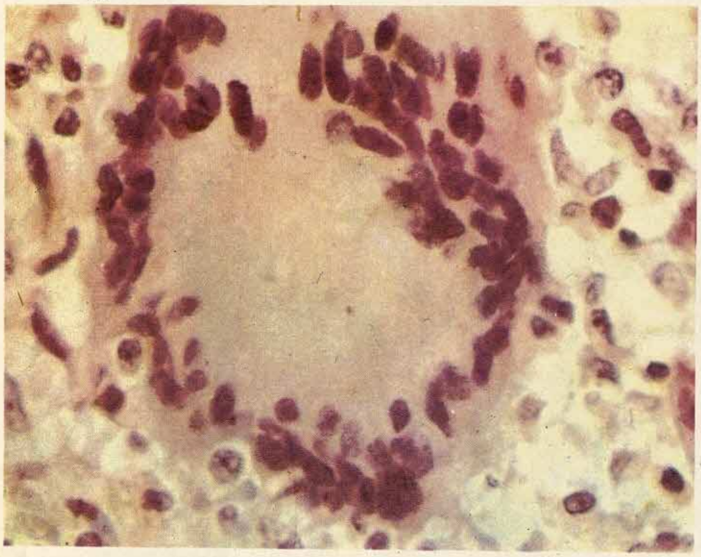
The host's body usually has several mechanisms of defense against pathogens; and the ability of the pathogen to spread throughout the host's body depends on possession by the microbe of any of several substances that counteract the defenses. Many virulent bacteria are surrounded by capsules of gelatinous material that protect them from the white blood cells that would otherwise surround and ingest them in amoeboid fashion. Some bacteria produce leucocidins that kill white blood cells (leucocytes); others produce lecithinase, which dissolves red blood cells. The cells of most tissues are held together by the intercellular substance hyaluronic acid; some bacteria produce the enzyme hyaluronidase, which catalyzes the digestion of hyaluronic acid. This action separates the host's cells and permits the rapid penetration of the bacteria into the tissues.

Many bacteria exert their effect through their production of toxins, substances that are highly poisonous to the host. There are two general types of toxins: exotoxins, which are secreted by living cells; and endotoxins, which are not released until after the death of the cells that produced them. Exotoxins generally are proteins, and among them are some of the most poisonous substances known. Particularly notorious in this respect is the toxin of *Clostridium botulinum,* which causes a deadly form of food poisoning known as botulism. *Clostridium* thrives under anaerobic, neutral conditions, where it produces its toxin. Improperly canned fish, beans, or meats are ideal places for its growth. Only a small taste of contaminated food may be lethal. The organisms themselves need not be ingested; the toxin alone is enough to cause paralysis and death. Fortunately, this toxin, like many exotoxins, is destroyed by heat, and any suspect food can be boiled for ten or fifteen minutes to make it safe. Tetanus, anthrax, and diphtheria are a few other diseases associated with the production of exotoxins.

Endotoxins are complexes of proteins, lipids, and carbohydrates, and are not destroyed by the application of heat. They are produced by a variety of pathogens, particularly those that live in the intestinal tract. Endotoxins cause nausea, diarrhea, and fever, symptoms of many gastrointestinal diseases.

The significance of the small size of microorganisms is well illustrated by their toxicity. The smaller the organism, the larger the ratio of its surface area to its volume. Millions of minute cells together have many times the surface area of a single large cell of the same volume. Because the rates of production and secretion of toxins are related to the amount of surface area available, large

4a



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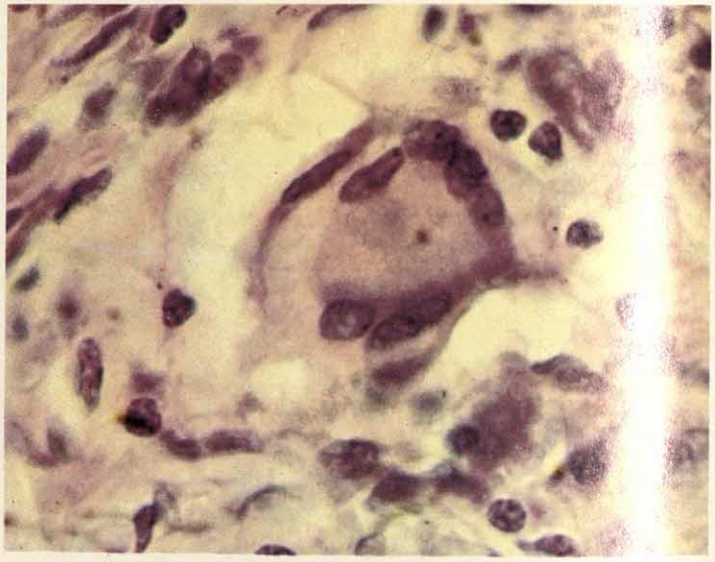

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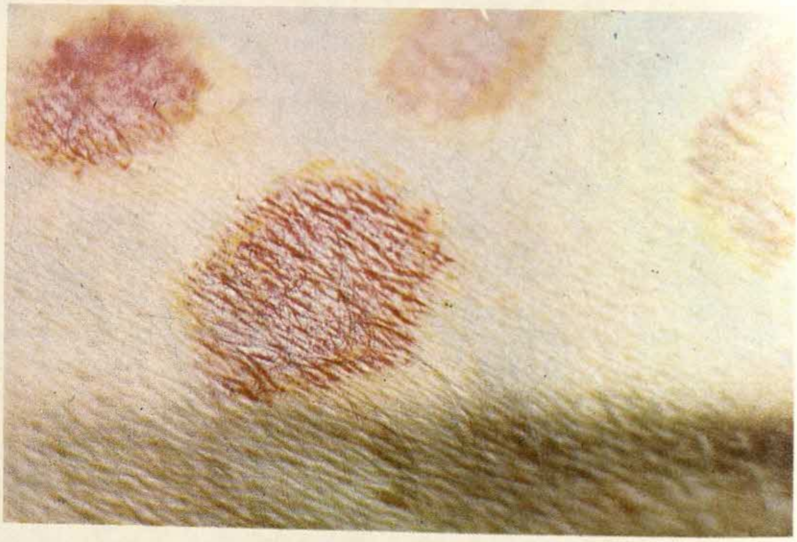


TUBERCLES—*Mycobacterium tuberculosis* is the agent of tuberculosis. It usually enters the body by way of the mouth or nose and reaches the alveoli of the lung. The cells of the lung begin to grow around the infection, forming tubercles (Illustration 4a). In this way the bacteria are isolated from the rest of the body. If the host's resistance is high, the infection may spread no farther, and he may become immune. The cells contributing to the formation of a tubercle are large, and they have many nuclei arranged at the periphery of the cytoplasm (Illustration 4b).

TUBERCULIN REACTION—Tuberculin is an extract of cultures of *Mycobacterium tuberculosis*. The tuberculin test is performed by injecting a minute quantity of the concentrated extract (or the dead bacteria) into the skin. A hard red pustule 5 to 24 mm in diameter (Illustration 5) appears at the site of injection after 24 to 48 hours if the person has tuberculosis or has had it.

number of minute organisms can produce great quantities of toxins in a short period of time.

DISEASES CAUSED BY MICROORGANISMS

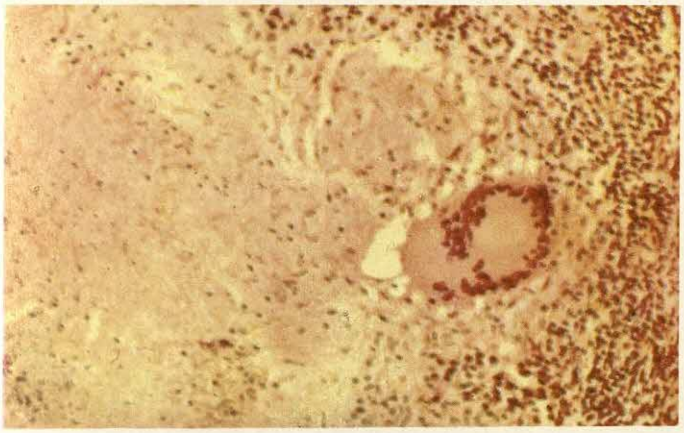
The number of diseases caused by microorganisms is large. A few of those caused by bacteria and the causative organism are: tuberculosis (*Mycobacterium tuberculosis*); leprosy (*Mycobacterium leprae*); bubonic and pneumonic plague (*Pasteurella pestis*); pneumonia (*Diplococcus pneumoniae, Klebsiella pneumoniae,* and others); diphtheria (*Corynebacterium diphtheriae*); typhoid fever (*Salmonella typhosa*); cholera (*Vibrio comma*); tetanus (*Clostridium tetani*); syphilis (*Treponema pallidum*); and gonorrhea (*Neisseria gonorrhoeae*).

Among the diseases caused by protozoa are African sleeping sickness (*Trypanosoma gambiense*), amoebic dysentery (*Endamoeba histolytica*), and malaria (*Plasmodium vivax* and other species).

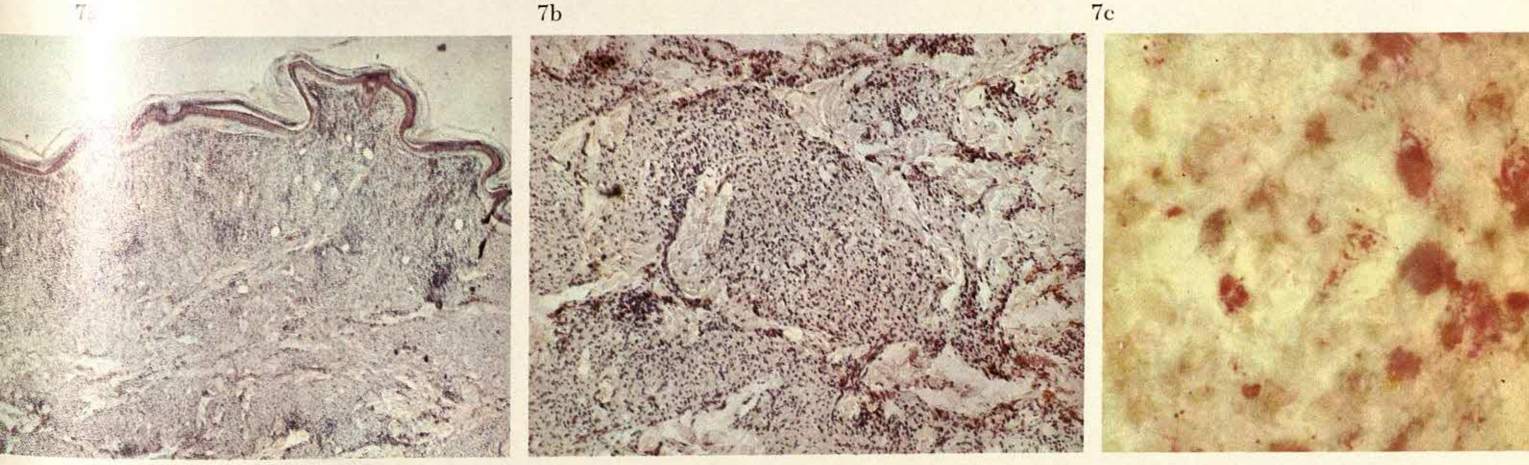
Diseases caused by viruses include the common cold, influenza, poliomyelitis, smallpox, yellow fever, and measles.

Ringworm and athlete's foot are two diseases caused by fungi.

6



TUBERCULAR LUNG—If the host's resistance is low, the tuberculosis bacteria multiply in the tubercle, which may then become the center for further infection. The bacteria destroy the cells of the host, and the center of the tubercle becomes filled with a yellow mass of dead cells. This material resembles cheese in appearance and is called caseated material. As tubercles grow, adjacent tubercles may fuse. Gradually more and more lung tissue is destroyed. In advanced cases of tuberculosis, persons typically cough up caseated material that may be mixed with blood when blood vessels have been damaged. This photograph (Illustration 6) shows a small section of an infected lung.



SKIN OF A LEPER—These photographs show skin infected with the bacterium of leprosy (*Mycobacterium leprae*). Nodules containing the bacteria are formed in the skin and along the nasal passages. Nerves may also be infected. Deep tissue is rarely affected. Illustration 7a is a microscopic section of leprous skin; the epidermis is thin and there is a slight increase in the thickness of the stratum corneum. The superficial dermis is completely reduced, while the middle and deeper layers of the dermis are invaded by bacterial cells. An enlargement is shown in Illustration 7b. Illustration 7c shows a preparation in which groups of leprosy bacteria are particularly evident in the cells.

CYTOPLASM AND THE CELL MEMBRANE

a voyage around the cell's nucleus

THE STRUCTURE OF CYTOPLASM

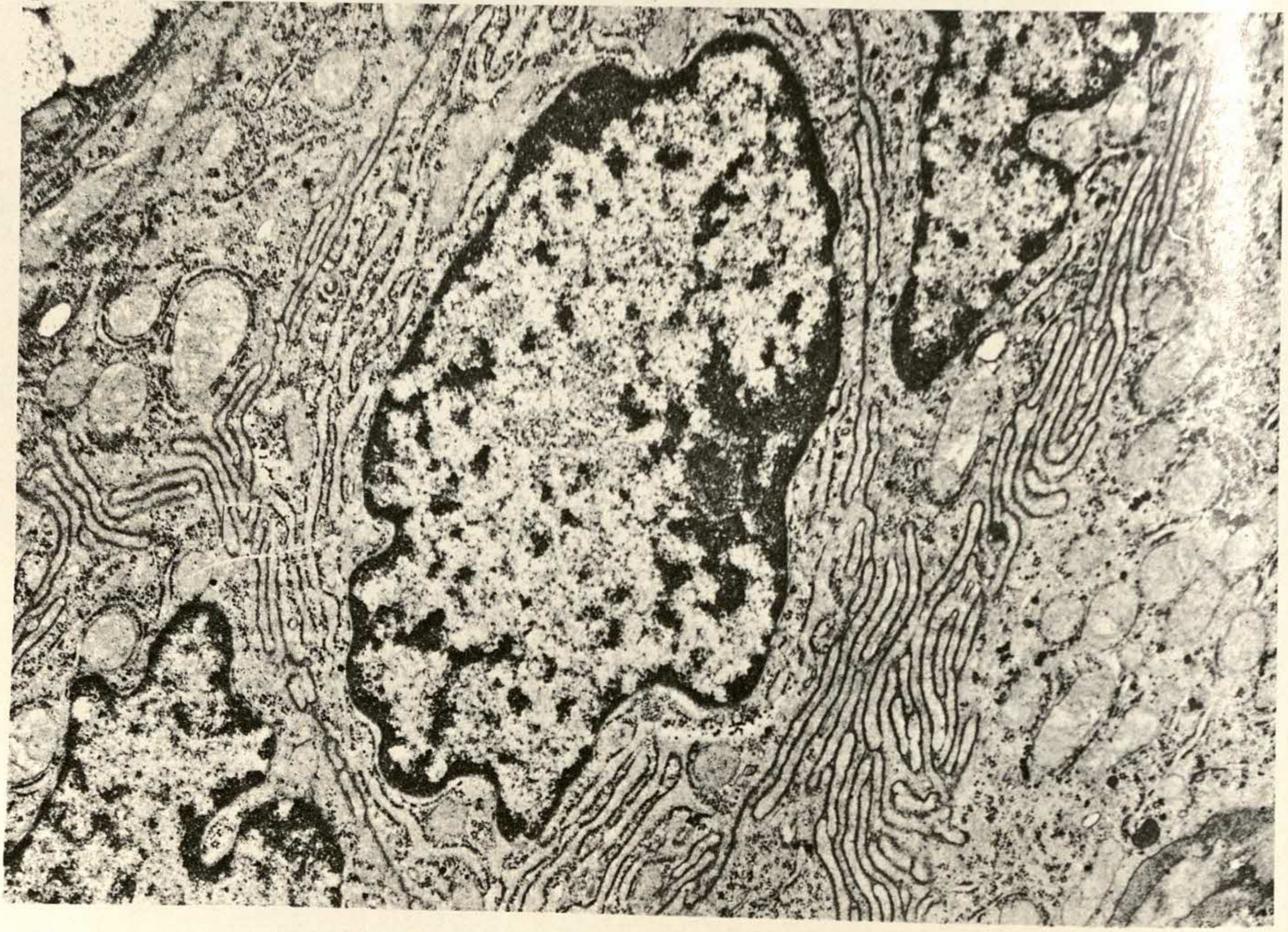
The cell is a living thing that grows and reproduces itself. The nucleus, the element indispensable to the life of the cell, functions in harmony with all the other parts of the cell. This correlation follows one of the basic laws of biology: each part, each organelle, and each organ functions in relation to all other parts, organelles, and organs. Even in this submicroscopic world, nature has created a "society" in which no element is an end unto itself but is an integral part of a harmonious whole. Each cell contains all the basic components that are necessary for its vital functions.

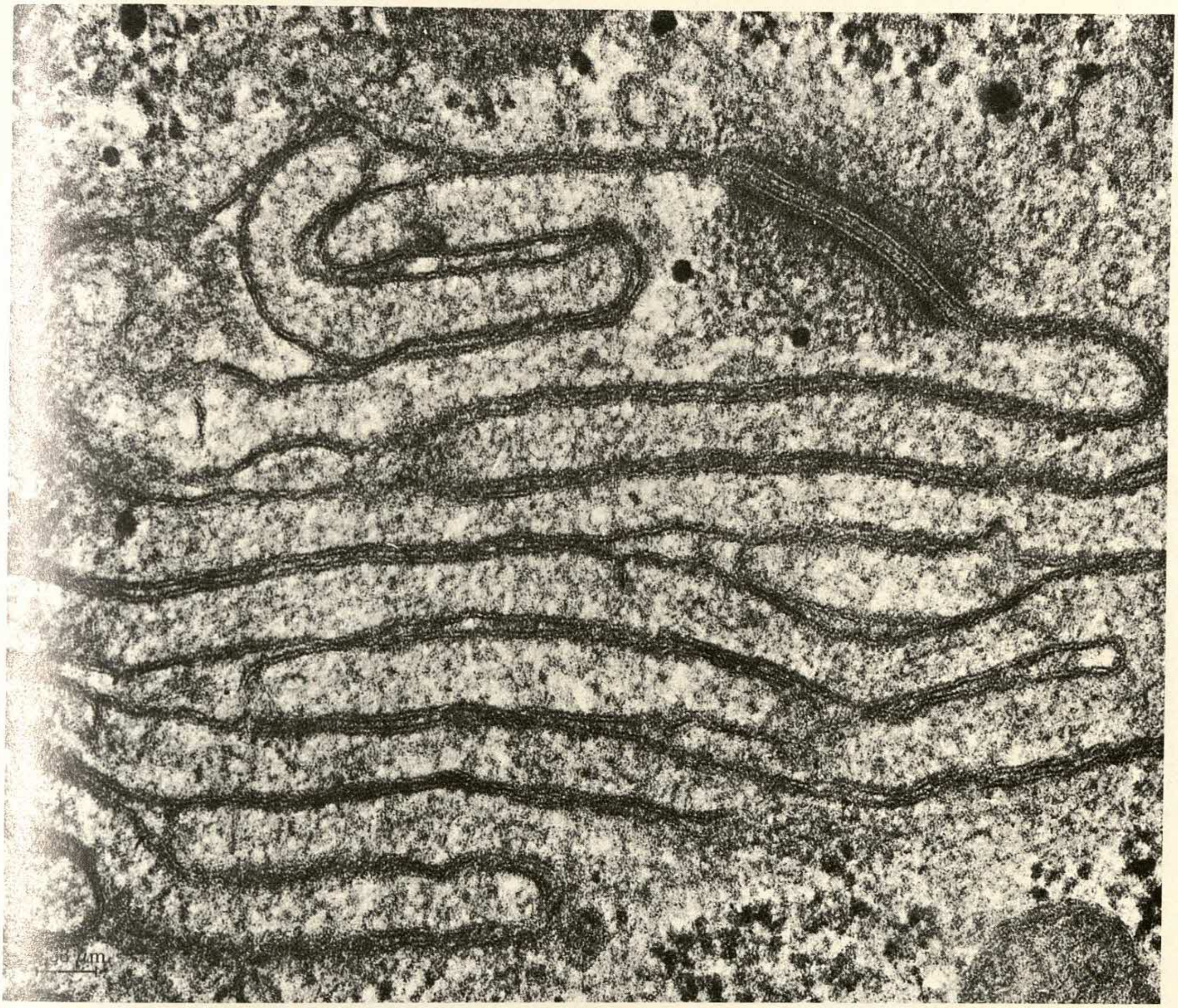
The nucleus, the cytoplasm, and the cell membrane enclosing the whole are the three main parts of a cell. Cytoplasm appears under a conventional microscope as a homogeneous, transparent, jellylike mass. If cytoplasm is examined through an electron microscope or by x-rays, its complex physicochemical structure, known as cytoplasmic ultrastructure, is revealed. Only those optic systems that can magnify details up to a thousand times more than a conventional microscope will reveal cytoplasmic ultrastructure, which sometimes seems to have a reticular nature (Illustration 1) and at other times appears as a granular mass, according to the type of cell and the circumstances of the moment.

The capacity of cellular material to take on different structural aspects is one of its characteristics and is known as cellular metastability. The reticulum and granule are composed essentially of proteins formed of large molecules that are sometimes linked to constitute aggre-

CELLS OF THE HUMAN INTESTINE—Under the electron microscope, the reticular structure of cytoplasm is clearly visible.

1





2

CELLS OF THE HUMAN INTESTINE UNDER THE ELECTRON MICROSCOPE—Cellular junctions and the convolutions of the cell membranes are clearly visible. Each membrane is composed of three strata: two dense layers that are made up of protein and one clearer, transparent layer of lipids.

gates. The amount of water in the interstices of the reticulum increases or decreases according to the cell's needs. In the process, the volume of the cytoplasm is increased or decreased. Thus, the interstices are not stable structures but can dilate or contract to the point of disintegration and successive recomposition.

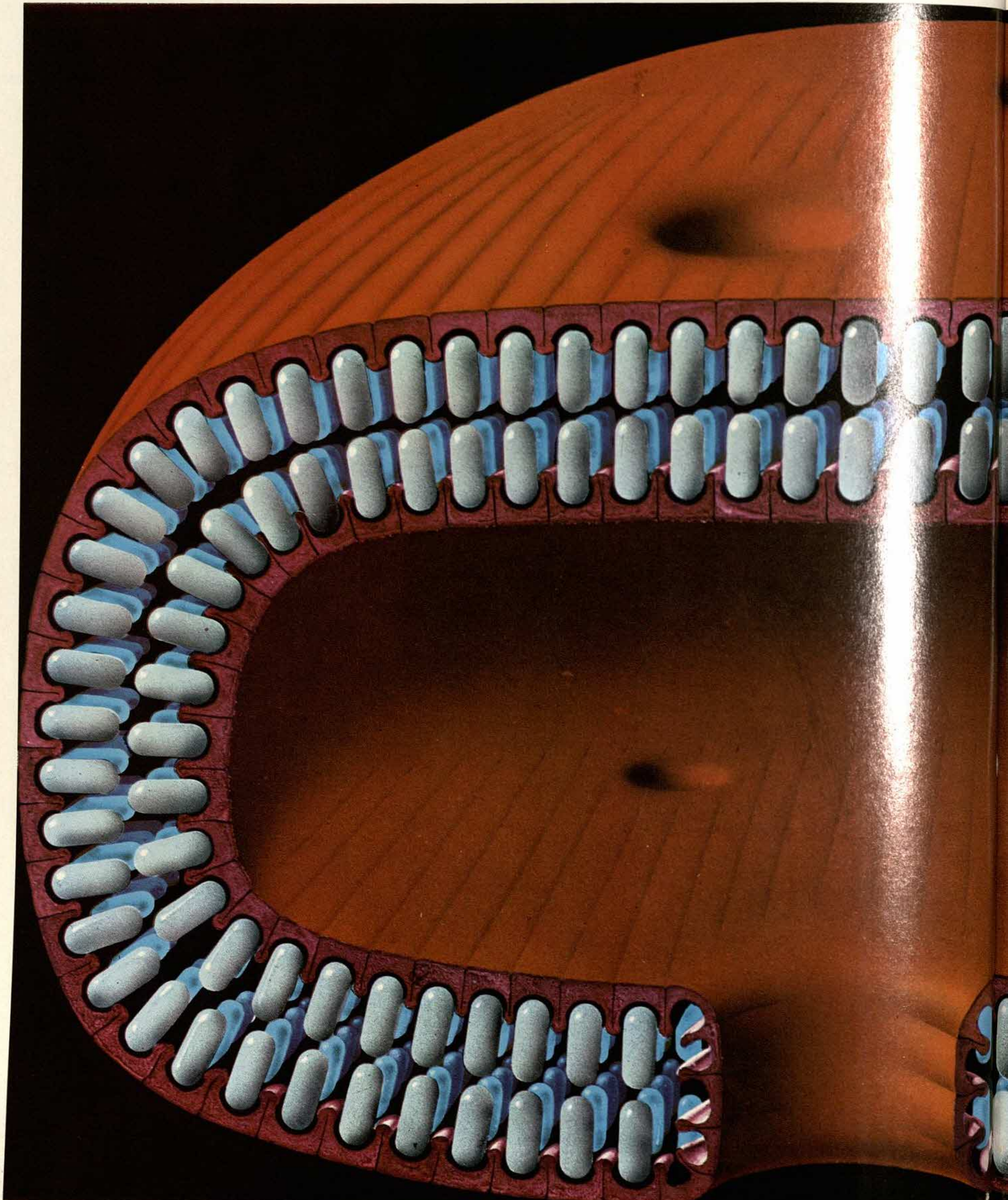
It is possible to observe a similar effect by placing a strip of gelatin first in a solution of water and common kitchen salt, and then in a solution containing another type of salt. After a while, the strip of gelatin expands. This property of cytoplasm—known as its colloidal characteristic—is determined by the protein that it contains.

COLLOIDS AND CRYSTALLOIDS

In 1860 a Scottish chemist, Thomas Graham, noticed that when he immersed certain substances (paste, gelatin, albumen, and starch) in a liquid, they diffused very slowly, at a rate at least 100 times slower than certain other substances, such as salt and sugar. Graham also noted that these latter substances differed from the others in their capacity, when in solution, to pass through a membrane—in this case a film of nitrocellulose. In fact, when a bladder of collodion (the film produced when a nitrocellulose and ether solution is dried quickly) is filled with a mixture of sugar and paste and placed under running water, the sugar quickly passes through the membrane and is carried away by the water, while the paste remains inside the membrane. A substance's capacity to pass through a membrane depends on the dimensions of its molecules. Graham pointed out the notable difference that exists between what he called crystalloids—ordinary soluble substances, such as

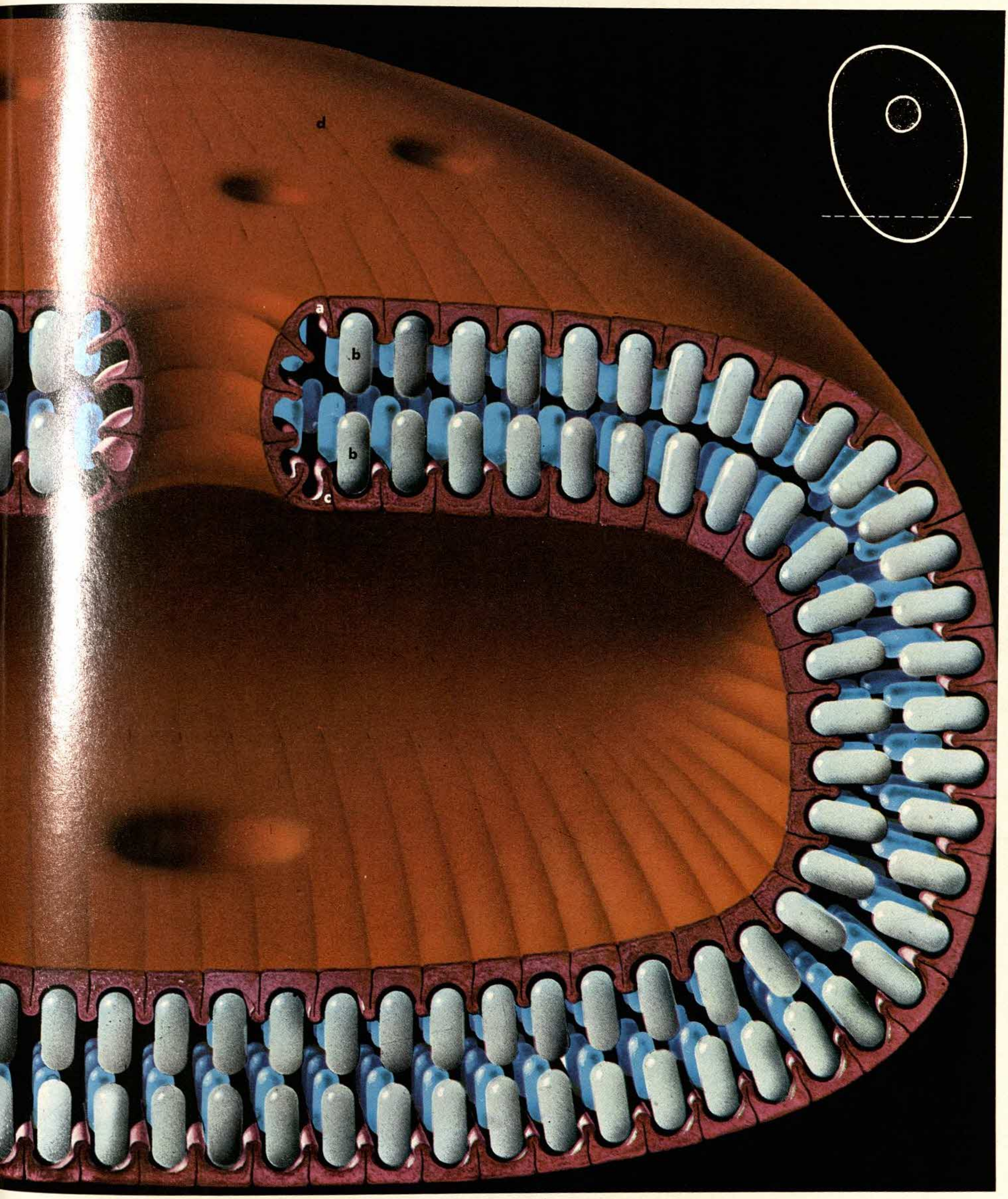
3

THE CELL'S DEFENSIVE BARRIER—**a** An external stratum of protein molecules parallel to the membrane's surface; **b** a double intermediate stratum of lipid molecules arranged perpendicularly to the protein molecules; **c** internal stratum of protein molecules having the same characteristics as those of the ex-



ternal stratum; **d** pores, the openings that interrupt the membrane's continuity.

The illustration corresponds to an enlargement of about 4 million times. Above, at the right, is a schematic diagram of the cell and the axis along which the section was made.



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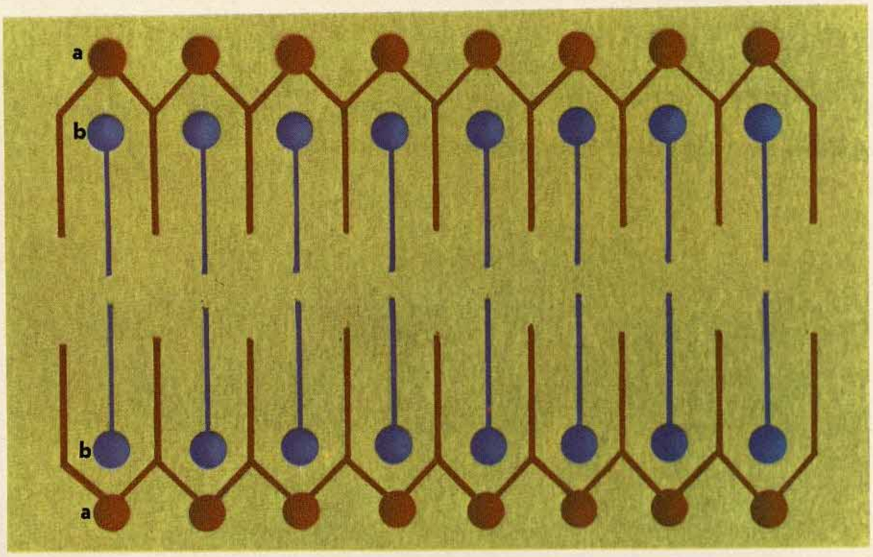


SCHEMATIC DIAGRAM OF THE CELL MEMBRANE—**a** proteins; **b** lipids.

kitchen salt and sugar, that crystallize and pass quickly through membranes—and colloids—substances that are not diffusible and that pass very slowly through membranes.

The classification of all these substances is no longer based on whether or not the molecules pass through a membrane (which is called semipermeable if they do), but is based on the dimensions of their molecules. Thus, true solutions are those in which the dispersed molecules have a diameter of less than 0.001 μm (about .004 × 10^{-5} in.), as in a solution of sugar and water, while colloidal solutions are those in which the diameter of the colloidal particles ranges from 0.001 to 0.1 μm (about 0.4 × 10^{-5} in.), as in cytoplasm. Suspensions are those substances in which the particles have a diameter of more than 0.1 μm, as in fog and smoke.

On the basis of this classification, true solutions in which the dispersed phase (the dispersed particles) is not distinguishable from the dispersion medium (the liquid in which the particles are dispersed) are known as single-phase systems. Colloidal solutions and suspensions in which the dispersed phase is distinguishable from the dispersion medium are called two-phase, or polyphase, systems. Cytoplasm, which is composed essentially of substances in the colloidal state, is a two-phase system.

THE STRUCTURE AND FUNCTION OF THE CELL MEMBRANE

The cell membrane is a film that separates the cytoplasm from its surroundings. In animal cells this membrane is not distinct from the cell itself because it is a thickening of the cytoplasm, which becomes denser from the center of the cell outward, forming a true membrane on its surface. The different reactions of the cytoplasm in contact with its surroundings regulate the various exchanges between the cell and its environment.

The ultrastructure of the cell membrane is composed of three superimposed layers: two made up of proteins, and the intermediate layer composed of lipids, or fats. Under the electron microscope, the first two appear to be dark and dense, while the central layer is clear (Illustration 2). The cell membrane also has openings, like pores, that communicate with the internal elements of the cell. Through these pores enter the nutritive substances necessary to the life of the cell and through them the cell's wastes, or catabolites, are eliminated.

Like the rest of the cell's components, the membrane is not a stable structure but a dynamic one that changes its arrangement and form according to the needs of the cell. Its function is primarily selective, since it permits the passage of certain substances only—those that are indispensable to the life of the cell and whose molecules have a diameter smaller than, or equal to, that of the pores in the membrane. Further, since the membrane is formed of lipids as well as proteins (Illustration 3), and these lipids constitute a true barrier, the more liposoluble (soluble in fats) a substance's molecule is, the more quickly it penetrates the membrane.

Irregularities in the form of extensions and cavities occur in the cell membrane, increasing its surface area and capacity for absorption. The extensions contain apparently structureless cytoplasm. The cavities, or cups, pinch off, passing liquid across the membrane in the form of a vacuole. This phenomenon is known as pinocytosis, or "surface drinking."

The cell membrane also acts as a defensive barrier against harmful stimuli that may come from the cell's environment and thus performs a real protective function. On the other hand, its permeability is a very important factor in establishing within the cell the physiological conditions necessary to its life.

The cell membrane, then, is one of the essential elements in cell life. Without it, the cell's vital substances would be scattered and lost; through it, the cell takes in necessary substances and eliminates wastes; by means of it, the cell responds and reacts to external stimuli.

THE CELL ORGANELLES

the harmonious integration of functions in the cell

Most cells are so small that they cannot be seen without a microscope. A living cell placed in a drop of water and viewed under an ordinary compound microscope may appear to be clear or to contain a few small structures called organelles. If the cell is sliced into thin sections that have been impregnated with special biological stains, the compound microscope may reveal more organelles with a suggestion of what seems like a kind of internal structure. Only when extremely thin cell sections are magnified several thousand times by an electron microscope does the fantastic detail and intricacy of the cell become apparent.

Protoplasm, the living portion of a cell, has a semifluid consistency. It is enclosed by a unit membrane composed largely of proteins and lipids. Many of the organelles in the protoplasm consist, at least in part, of similar unit membranes. The protoplasm of a plant or animal cell ordinarily contains one nucleus, a spherical or nearly spherical organelle. The remaining portion of the protoplasm is the cytoplasm. Among the organelles in the cytoplasm are the mitochondria, the endoplasmic reticulum, the Golgi apparatus, lysosomes, and centrioles.

MITOCHONDRIA

Mitochondria, or chondriosomes (Illustration 1), are rodlike, spherical, or filamentous organelles. Their smallest diameter is about 0.5 μm (about .0000195 in.), and the longest diameter may reach 2.0 μm (about .000078 in.) or more.

Each mitochondrion is bounded by a pair of unit membranes, one inside the other. The inner membrane folds inward, forming partitions known as mitochondrial cristae (Illustration 2). The cristae may be few or numerous and are of various shapes. They increase the surface area of the internal membrane on which are located some of the enzymes essential for cellular respiration. It is this respiratory process that releases from food molecules the energy that the cell needs to perform nearly all its vital functions; as the cell's organelle of respiration, the mitochondrion is also its energy center. The fuel that produces this energy is the sugar, glucose. In the cytoplasm, glucose is first broken down to pyruvic acid by a process known as glycolysis. Pyruvic acid then enters the mitochondrion, where it is further broken down (Illustration 3).

Inside the mitochondrion, the enzymes on the cristae convert pyruvic acid to carbon dioxide and water by a series of chemical reactions that release energy. This energy activates many of the vital processes of the cell. Because of this, mitochondria are absolutely necessary to the existence of most plant or animal cells.

Mitochondria are most numerous in cells that expend a great deal of energy, and they often cluster in the most active part of the cell.

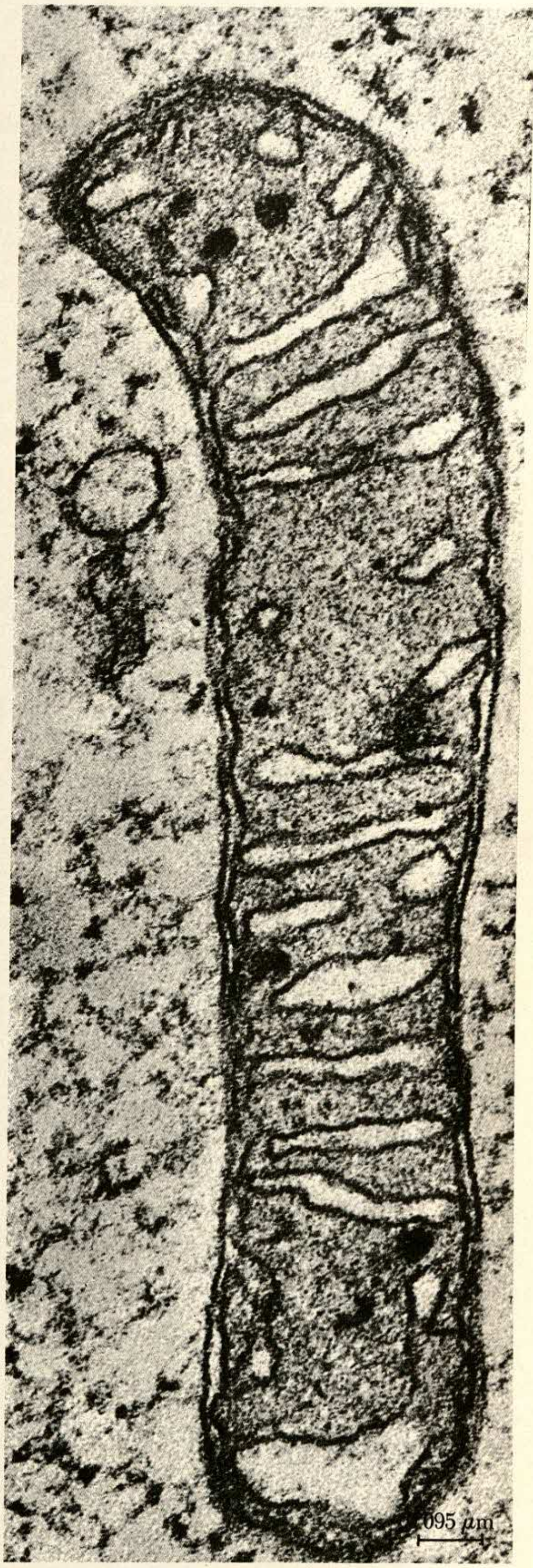
ENDOPLASMIC RETICULUM

Most of the cytoplasm has a very intricate ultrastructure, visible under the electron microscope as a complex of paired unit membranes. This complex constitutes the endoplasmic reticulum, or ergastoplasm (Illustration 4). When the complex is composed solely of membranes, it is known as a smooth endoplasmic reticulum; when it is made up of membranes to which many granules are attached, it is called a rough endoplasmic reticulum. These granules are the ribosomes; they have an essential role in protein synthesis. The endoplasmic reticulum links several other organelles with one another; it also transports substances to various parts of the cell and may expel them from the cell.

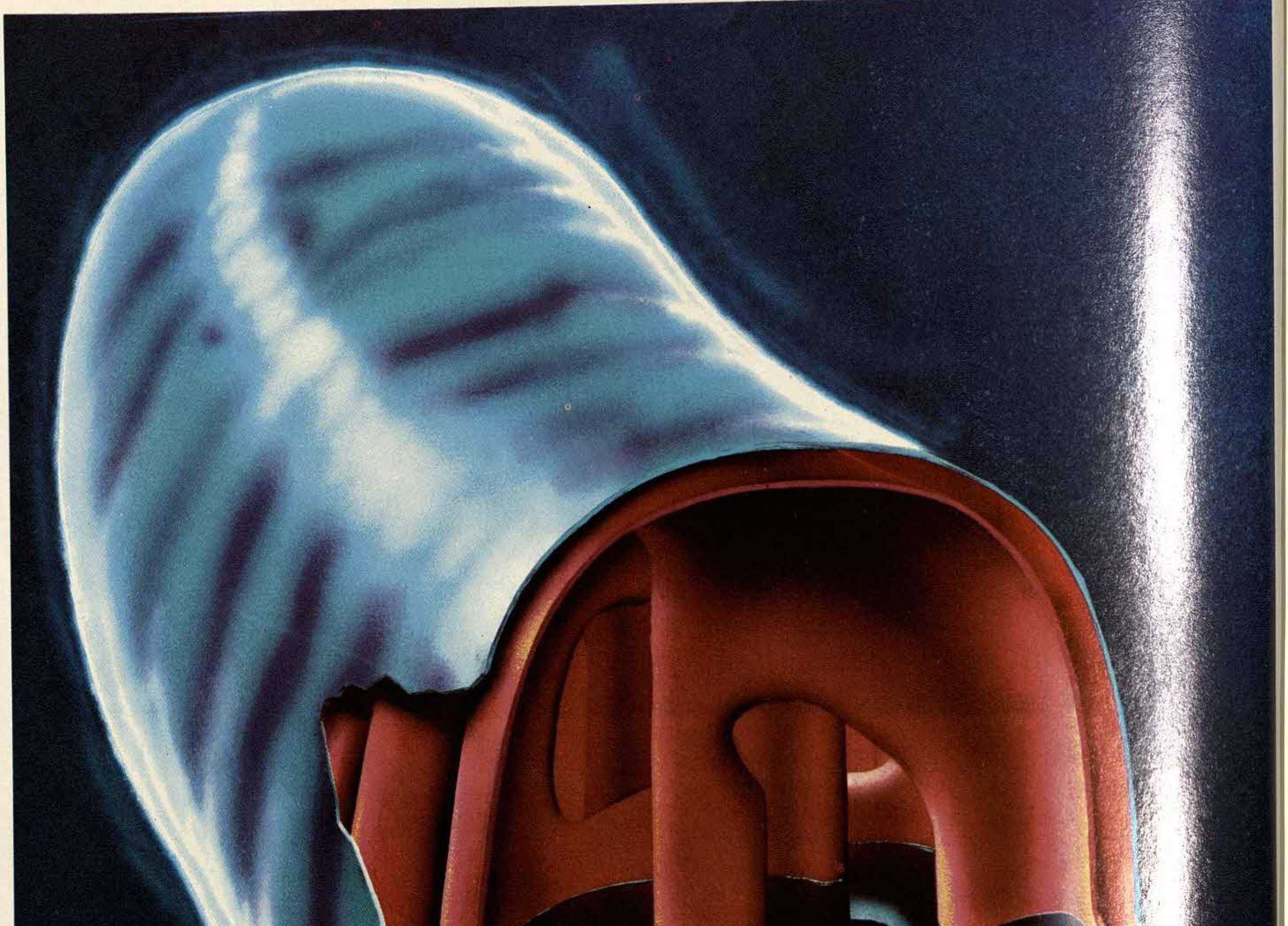
THE GOLGI APPARATUS

The Golgi apparatus (Illustration 5) takes its name from the Italian scientist Camillo Golgi, who discovered it in 1898. This organelle is similar to the endoplasmic reticulum in being composed of a system of lamellae and cavities in a parallel arrangement. The Golgi apparatus occurs in many kinds of cells, but is most common in glandular and other secretory cells. It is believed to function in secretion of materials and perhaps also in their synthesis and storage.

1



A MITOCHONDRION UNDER THE ELECTRON MICROSCOPE—The two unit membranes and the mitochondrial cristae are clearly visible. Some of the cristae extend across the mitochondrion.



THREE-DIMENSIONAL VIEW OF A MITOCHONDRION—Within the outer unit membrane of the mitochondrion lies another membrane that folds inward, forming the cristae in the cavity of the organelle. Liquid fills the interior of the mitochondrion. The illustration is about 1½ million times actual size.

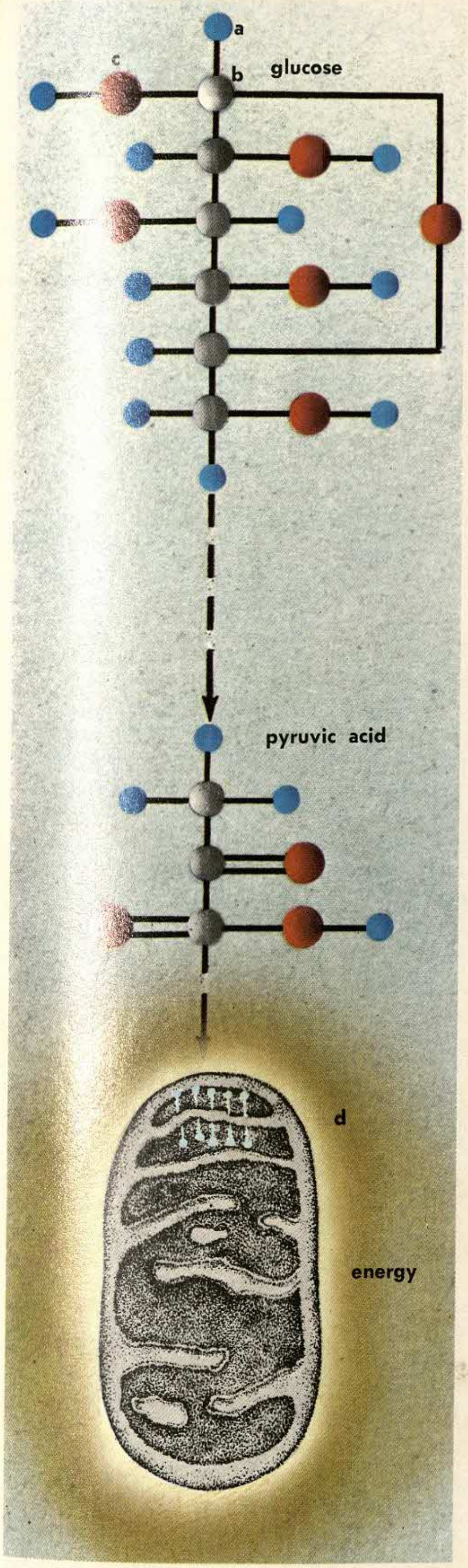


DIAGRAM OF GLYCOLYSIS—**a**-hydrogen; **b**-carbon; **c**-oxygen; **d**-enzymes.

LYSOSOMES

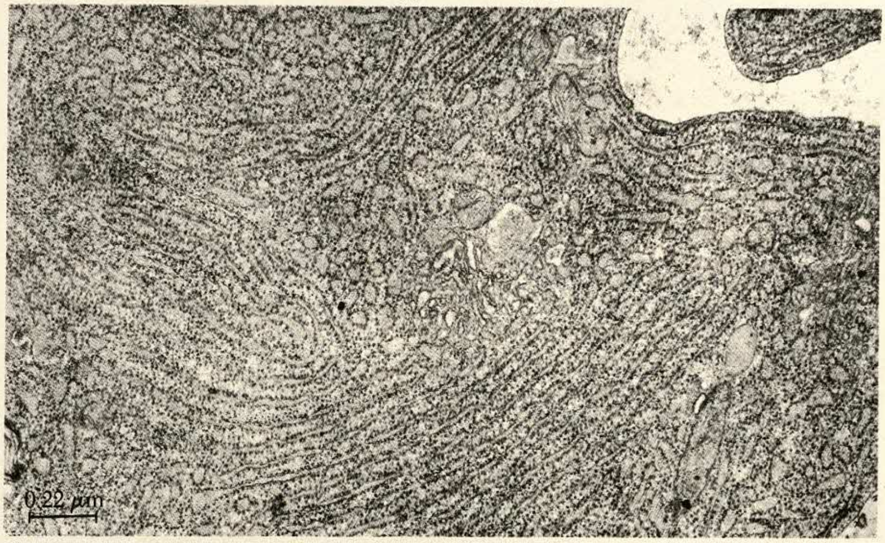
The electron microscope reveals lysosomes, saclike organelles believed to contain enzymes that digest large food molecules to smaller ones that can be assimilated by the cell. Old, no longer functional, organelles may also be digested by enzymes of the lysosomes.

CENTRIOLES

Animal cells contain a pair of centrioles in the cytoplasm, near the nucleus. Each centriole is cylindrical and contains nine filaments. A zone of cytoplasm known as the centrosome surrounds the centrioles. The centrioles function during mitosis.

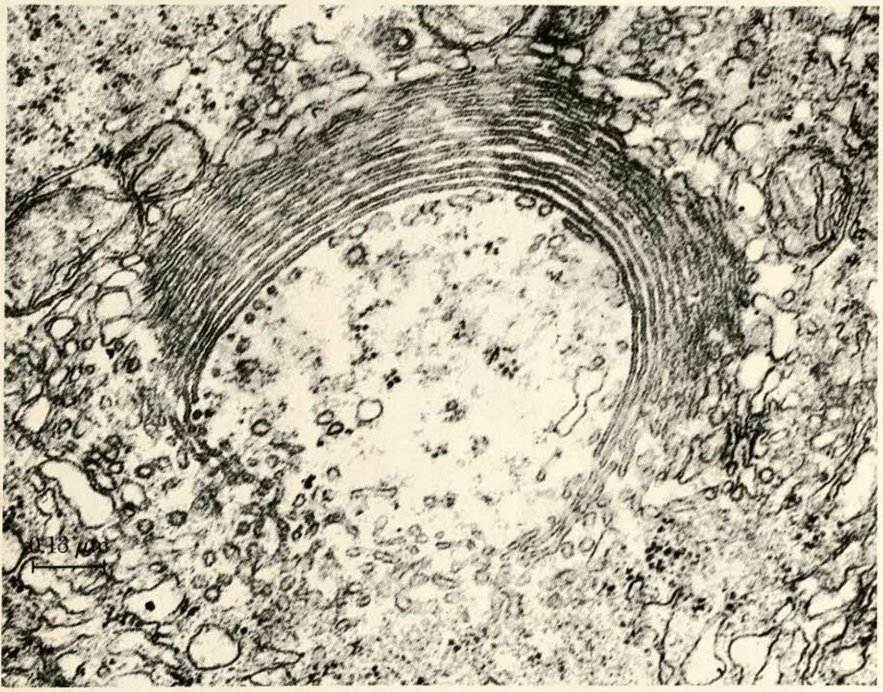
4

ENDOPLASMIC RETICULUM UNDER THE ELECTRON MICROSCOPE—The ribosomes, or granules (Illustration 4), are visible along the membranes.

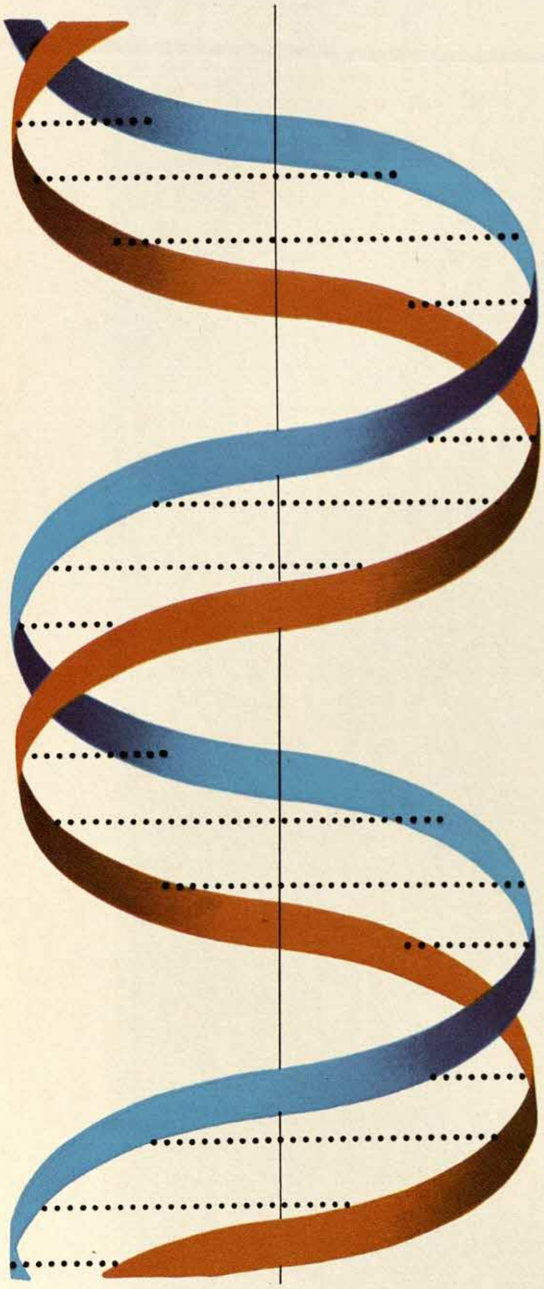


THE GOLGI APPARATUS UNDER THE ELECTRON MICROSCOPE — The Golgi apparatus (Illustration 5) consists of a series of membranes parallel to each other.

5



THE FUNCTION OF THE NUCLEUS | control of the cell



THE SPIRAL OF LIFE—In this schematic representation of the helical arrangement of the two strands of the DNA molecule, the dotted lines represent the hydrogen bonds that unite the purine and pyrimidine bases.

Even the simplest living thing, a unicellular organism, is an amazing complex of molecules of diverse kinds and properties. The possibilities for chemical reactions among these molecules are so great that if they were not controlled in some fashion, the cell would be the location of a disorderly sequence of random reactions that might do it more harm than good.

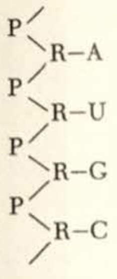
To proceed with any measurable speed, most chemical reactions in living things require the presence of enzymes. Because each reaction or group of similar reactions is catalyzed by a different enzyme, any method of controlling the presence or absence of a given enzyme also controls the reaction catalyzed by that enzyme. The function of controlling the synthesis of enzymes falls primarily to the nucleus, although organelles and compounds of the cytoplasm are also involved.

NUCLEIC ACIDS

Two distinct types of nucleic acids have been discovered in cells: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Each is a large polymer of high molecular weight consisting of repeating units called nucleotides. Each nucleotide, in turn, is formed from three molecules: phosphoric acid, a sugar, and a nitrogen base. The nitrogen bases are of two types: purines and pyrimidines. The sugars of DNA and RNA are different, and so are some of their pyrimidines. The constituents of DNA and RNA are listed in the following table:

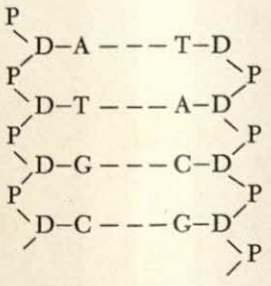
	DNA	*RNA*
acid	Phosphoric acid (P)	Phosphoric acid (P)
sugar	Deoxyribose (D)	Ribose (R)
purine bases	Adenine (A) Guanine (G)	Adenine (A) Guanine (G)
pyrimidine bases	Cytosine (C) Thymine (T)	Cytosine (C) Uracil(U)

The nucleotides of the nucleic acids are united through their phosphate and sugar groups. The result is a long chain consisting of alternating phosphate and sugar groups, with each sugar bearing to the side either a purine or a pyrimidine. Several hundred nucleotides may comprise a single nucleic acid molecule.



RNA

DNA differs from RNA not only in its sugar and one of its pyrimidines, but in its double strand (RNA is a single-stranded molecule). The two strands of DNA are held together by hydrogen bonds between the purines and pyrimidines of opposite strands. The adenine of one strand always is paired with the thymine of the opposite strand, and the cytosine always is paired with guanine.



DNA

The two strands are wound around each other, forming a double helix.

REPLICATION OF DNA

The replication of DNA, which ordinarily precedes mitosis, begins with the breaking of the hydrogen bonds between the two strands of the molecule and the unwinding of the double helix. Within the nucleus is a supply of nucleotides of the type comprising DNA. Each of the separated strands functions as a template and attracts to itself nucleotides complementary to its own nucleotides. This places the nucleotides in such a position that when they react with each other, the complementary strand is formed. Because both strands of the original DNA molecule function in this way, the result is two complete double-stranded DNA molecules identical with the original. Each consists of one strand from the original molecule and one newly formed strand.

THE GENETIC CODE

The genetic code resides in the order of the nitrogen bases of one strand of each DNA molecule. Each molecule contains the code for the synthesis of an enzyme. The enzyme is a protein, and each triplet, or set of three adjacent nitrogen bases in one strand, represents the code for one amino acid in the protein molecule. The order of the triplets along the DNA molecule determines the order in which the amino acids are assembled when the enzyme molecule is synthesized.

Because the DNA of the chromosomes is confined to the nucleus, and because proteins are synthesized on the ribosomes in the cytoplasm, the information residing in the genetic code must be transferred to the cytoplasm. This is done by RNA. Three types of RNA are involved in protein synthesis: ribosomal RNA, messenger RNA, and transfer RNA. Ribosomal RNA is present in the ribosomes, and it affords a site on which the protein is synthesized.

The synthesis of messenger RNA (mRNA) in the nucleus resembles that of DNA. One strand of the DNA molecule acts as a template on which a single strand of mRNA is formed. In this case, the nucleotides contain ribose rather than deoxyribose, and a nucleotide containing uracil rather than thymine is attracted to the position opposite the adenine of the DNA strand. In this way, the genetic code is transferred to the mRNA molecule, with uracil substituting for thymine in the code. The mRNA travels from the nucleus to the ribosomes in the cytoplasm where it is positioned temporarily

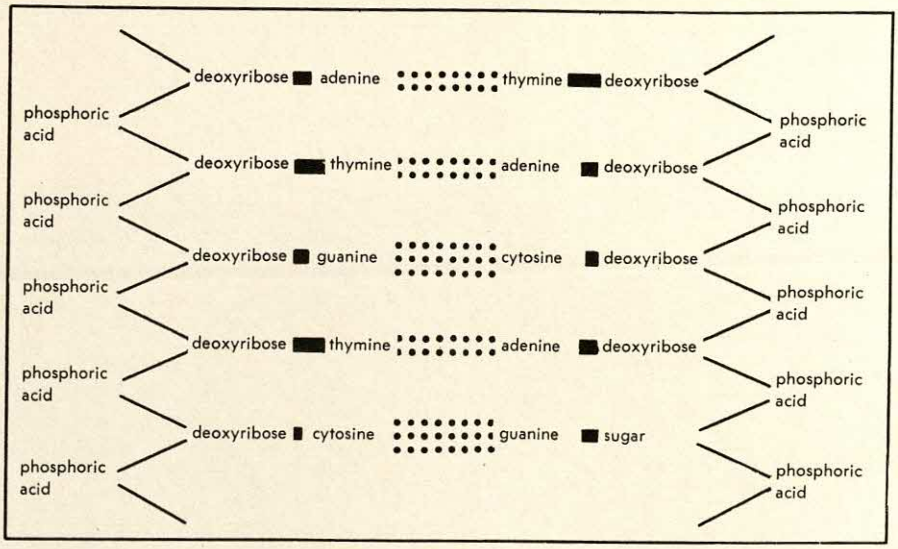
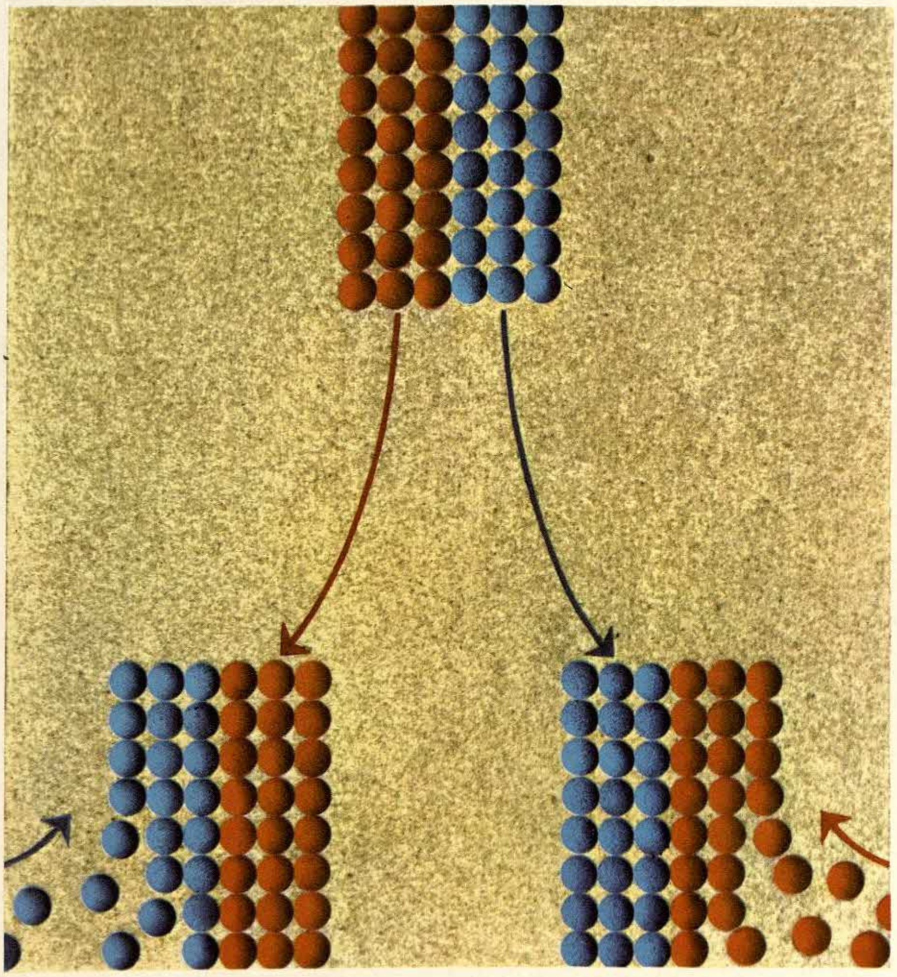
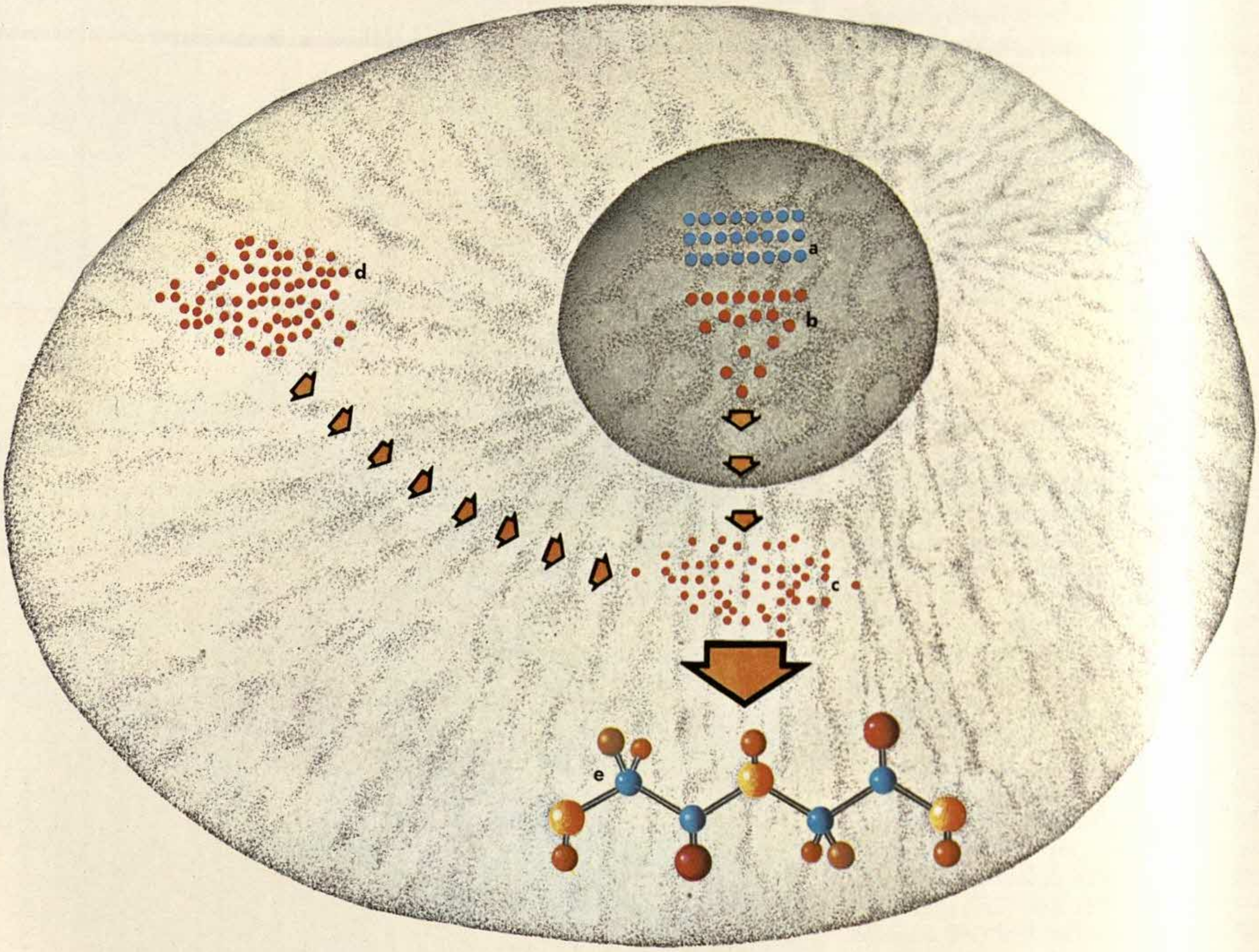

deoxyribose ■ adenine ⋮⋮⋮⋮ thymine ■ deoxyribose
phosphoric acid
phosphoric acid
deoxyribose ■ thymine ⋮⋮⋮⋮ adenine ■ deoxyribose
phosphoric acid
phosphoric acid
deoxyribose ■ guanine ⋮⋮⋮⋮ cytosine ■ deoxyribose
phosphoric acid
phosphoric acid
deoxyribose ■ thymine ⋮⋮⋮⋮ adenine ■ deoxyribose
phosphoric acid
phosphoric acid
deoxyribose ■ cytosine ⋮⋮⋮⋮ guanine ■ sugar
phosphoric acid
phosphoric acid

DIAGRAM OF DNA CHAINS—The bases are united by hydrogen bonds (dotted); adenine is always united to thymine by two hydrogen bonds, while guanine is always linked to cytosine by three hydrogen bonds.

REPLICATION OF DNA—The first step in the replication of DNA is the separation of this double-stranded molecule into two strands (red and blue dots represent the two strands). Each strand functions as a template to which complementary nucleotides are attracted. The nucleotides unite with the separated strands, forming complementary strands and completing the formation of two double-stranded DNA molecules.





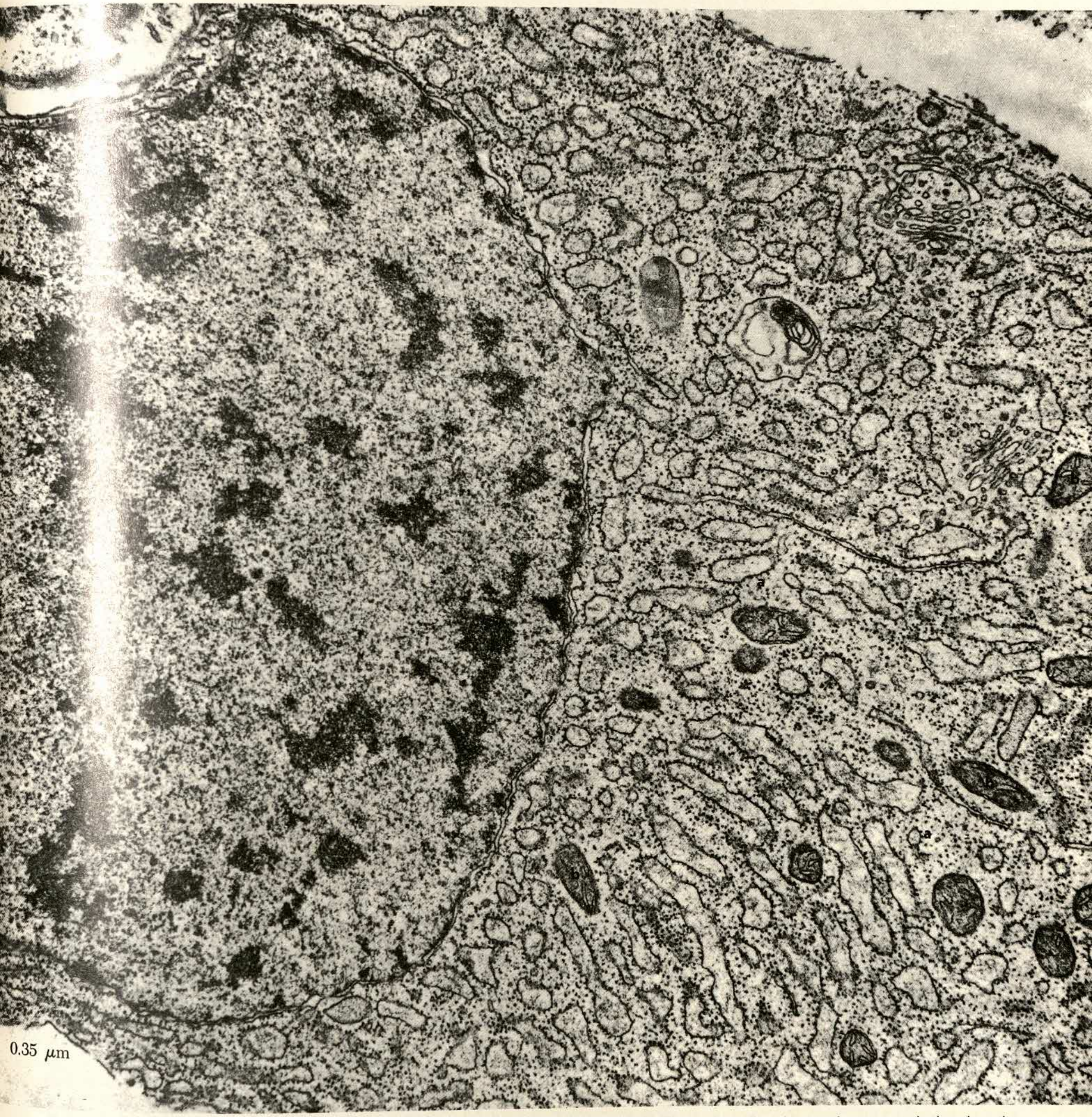
PROTEIN SYNTHESIS—**a** = DNA; **b** = mRNA; **c** = ribosomal RNA; **d** = tRNA; **e** = growing polypeptide chain.

on the ribosomal RNA.

Within the cytoplasm are several varieties of transfer RNA (tRNA) molecules. Each one is specific for one of the 20 naturally occurring amino acids, and each bears this amino acid at one end of the molecule. At another part of the tRNA molecule, a triplet of nitrogen bases is exposed. This triplet is different for each of the different tRNA types, and it is attracted only to its complementary triplet on mRNA. As mRNA moves across a ribosome, the appropriate tRNA molecules approach the mRNA in the exact order dictated by the genetic code of triplets that it bears. In this way, the amino acids are assembled in an order corresponding to the genetic code residing in the DNA molecules of the nucleus and carried to the cytoplasm in the mRNA molecule. As the amino acids are brought into correct position by the tRNA, they are released from the tRNA molecules; they then react with each other, forming a polypeptide. The polypeptide molecule may be a complete enzyme, or several may unite forming a larger molecule.

Because only some DNA molecules function at any one time, only certain mRNA molecules are present at that time. Only the corresponding enzymes are produced, and only the reactions catalyzed by those enzymes can occur. The functioning of different DNA molecules at appropriate times coordinates the chemical reactions occurring within the cell.

What turns particular DNA molecules "on" and "off" is not understood completely, but it is known that the presence of a given substrate can induce the synthesis of its enzyme, and that the accumulation of the product of a reaction represses the synthesis of an enzyme. In multicellular organisms, hormones produced in one part of the body may initiate the action of certain DNA molecules in the cells of another part.



COARSE ENDOPLASMIC RETICULUM—The left side of this electron micrograph is occupied by a nucleus. To the right is cytoplasm with small, spherical ribosomes **a.** Many of these line the membranous endoplasmic reticulum. Numerous mitochondria **b** are scattered throughout the cytoplasm.

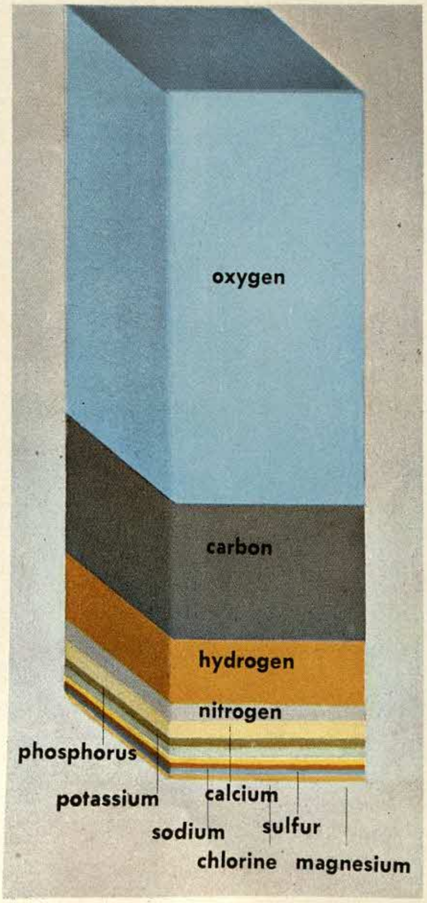
THE CHEMISTRY OF THE CELL—I | inorganic substances

All the vital processes of living things depend on specific chemical reactions among the diverse organic compounds that make up living matter. To understand the complex organic compounds of which organisms are composed, it is necessary to examine first the elements and inorganic compounds from which they are synthesized.

ELEMENTS ESSENTIAL FOR LIFE

Although virtually all the elements can be found in living cells, only a few of the 92 naturally occurring elements are a permanent part of the constitution of organisms or play an essential role in their metabolism. Most of the biologically important elements have low atomic numbers and low atomic weights. One of them, carbon, has the unusual property of being able to react with itself and form long chains or rings of carbon atoms. These chains and rings are the basis of the sometimes large and complex organic molecules that are not only characteristic of life but are an integral part of it. Most of the other essential elements react with the carbon and become part of the organic compounds.

COMPOSITION OF THE HUMAN BODY—The height of the colored bands is proportionate to the approximate amount of each element.



Essentially all organic compounds in living things contain carbon, hydrogen, and oxygen, the three most abundant elements in cells. They account for about 93 percent of the weight of the human body. Carbohydrates and fats contain only these three elements, although some of their derivatives may contain additional elements. Water, which is essential for all life, is composed of only hydrogen and oxygen.

Nitrogen is equally necessary for living things. It is a part of all amino acids, which are the constituents of proteins; and it is part of deoxyribonucleic acid (DNA), which is the genetic material, and ribonucleic acid (RNA), which functions in the synthesis of enzymes, which themselves are proteins. Carbon, hydrogen, oxygen, and nitrogen comprise about 97 percent of the human body by weight.

Several elements account for the remaining 3 percent. Some of them are present in large enough concentrations that they could be detected easily by the relatively crude methods of chemical analysis of a hundred years ago. These elements are called macronutrients. The micronutrients are present in such minute quantities that only the more refined methods of modern chemistry were able to detect their presence. Sometimes they are said to be present in traces, and for this reason they often are called trace elements.

MACRONUTRIENTS

The macronutrients include calcium, phosphorus, potassium, sulfur, chlorine, magnesium, sodium, and iron. Sodium is required by animals, but it is not known to be needed by plants. Iron is required in quantities intermediate between those of most macronutrients and micronutrients; for this reason it sometimes is classified with the latter group.

Calcium is a major constituent of the bones and teeth of animals and of the middle lamella, the cementing substance that holds the cells of plants together. It also plays an important role in the clotting of blood. Milk and its products are the main source of calcium in the west. In tropical and eastern lands, the bones of small fishes, certain cereals and vegetables, and sea salt are good sources.

ELEMENTAL COMPOSITION OF THE HUMAN BODY

oxygen	= 62.43	= 96.54%	total = 99.967%
carbon	= 21.15		
hydrogen	= 9.86		
nitrogen	= 3.10		
calcium	= 1.90	= 3.427%	
phosphorus	= 0.95		
potassium	= 0.23		
sulfur	= 0.16		
sodium	= 0.08		
chlorine	= 0.08		
magnesium	= 0.027		

Phosphorus is a constituent of several compounds found in all living cells: nucleic acids, both DNA and RNA; adenosine triphosphate (ATP), an energy-transferring compound; several coenzymes; and phospholipids, are components of the cell membranes. It is also an important constituent of bone.

Potassium is a macronutrient that is not known to become incorporated into organic compounds. Its role seems to be that of an enzyme activator.

Sulfur is part of three amino acids (cysteine, cystine, and methionine) and as such also is part of many proteins. It is also a constituent of coenzyme A.

Sodium and chlorine function in the maintenance of proper osmotic balance in animal cells, and are involved in the transmission of nervous impulses.

Magnesium is part of the chlorophyll molecule of plants and as such is essential in photosynthesis. It functions as an enzyme activator in both plant and animal cells and is one of the constituents of bone. Magnesium is also an important structural component of ribosomes.

Iron occupies the center of the heme molecule, which is a part of several enzymes associated with respiration, especially hemoglobin and the cytochromes. Recently it has been found to be a part of ferredoxin, a nonheme protein that catalyzes one step in the photosynthetic process.

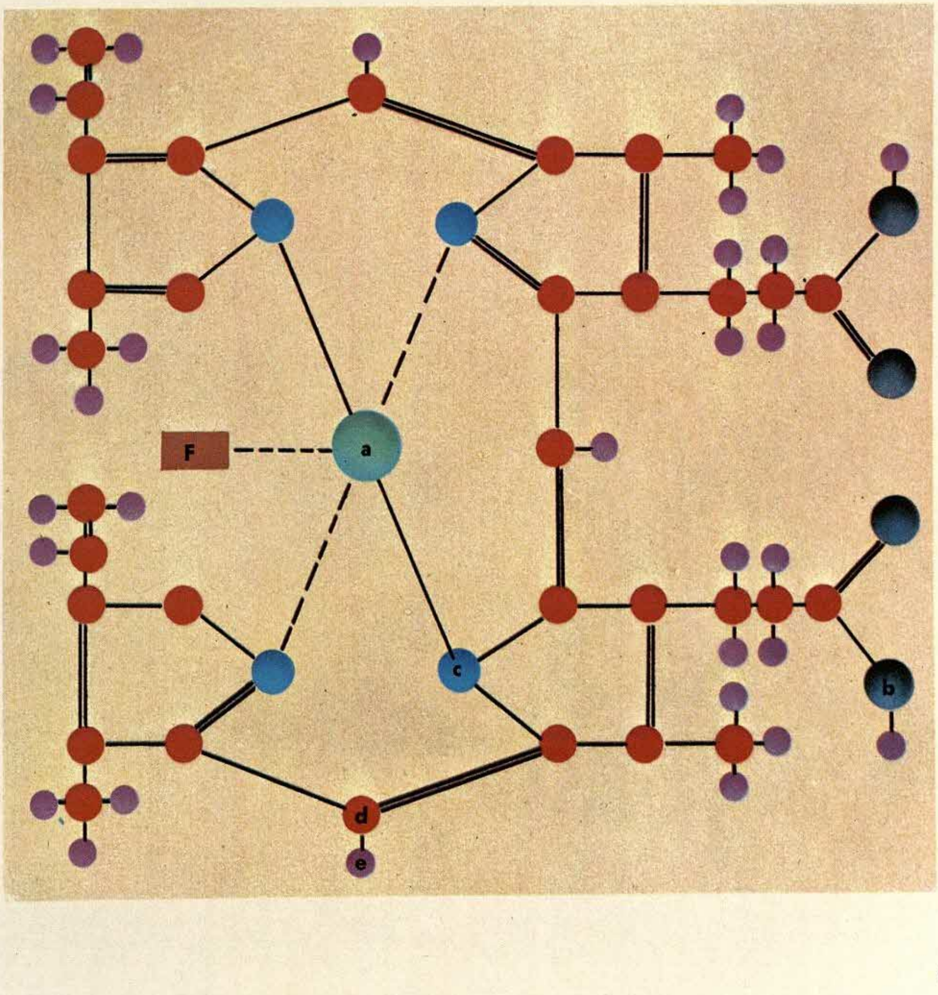
MICRONUTRIENTS

The micronutrients comprise only a small fraction of one percent of the living organism. They are required in such small quantities that they all probably function as parts of enzymes or as enzyme activators. Among them are manganese, copper, chromium, zinc, cobalt, molybdenum, boron, vanadium, selenium, iodine, and fluorine. Not all of them are known to be required by all organisms. At present, boron and molybdenum are known to be required by plants but not by ani-

ELEMENTS PRESENT IN LIVING ORGANISMS

NONMETALS	ATOMIC NUMBER	ATOMIC WEIGHT	METALS	ATOMIC NUMBER	ATOMIC WEIGHT
hydrogen	1	1.008	lithium	3	6.939
boron	5	10.811	sodium	11	22.9898
carbon	6	12.011	magnesium	12	24.312
nitrogen	7	14.0067	aluminum	13	26.9815
oxygen	8	15.9994	potassium	19	39.102
fluorine	9	18.9984	calcium	20	40.08
silicon	14	28.086	titanium	22	47.90
phosphorus	15	30.9738	vanadium	23	50.942
sulfur	16	32.064	manganese	25	54.9380
chlorine	17	35.453	iron	26	55.847
arsenic	33	74.9216	cobalt	27	58.9332
bromine	35	79.904	nickel	28	58.71
iodine	53	126.9044	copper	29	63.546
			zinc	30	65.37
			rubidium	37	85.47
			molybdenum	42	95.94
			cesium	55	132.905

HEME—The red respiratory pigment hemoglobin consists of a protein and four heme molecules. The iron atom in each heme molecule combines with oxygen which it transports from the lungs to other tissues of the body. (**a** = iron, **b** = oxygen, **c** = nitrogen, **d** = carbon, **e** = hydrogen.)



LIFE BEGAN IN WATER—This sea anemone (*Attinia celenterato*), like most other animals, lives in water. Even terrestrial animals are dependent on water and contain an internal supply in their body fluids. (3 X)

[illegible]; and vanadium may be needed by only a few plants and invertebrates.

Many trace elements are poisonous if present in the living cell in more than trace quantities. Advantage sometimes is taken of their toxic properties. Copper compounds, for instance, are used to kill algae in farm ponds; and some ointments containing zinc are used to discourage the growth of fungi on sores and wounds.

SOURCES OF NUTRIENTS

Both plants and animals obtain nearly all the elements they require in the form of compounds rather than in elemental form. Plants receive their carbon from the carbon dioxide gas of the air and most of their hydrogen from the water they absorb from the soil. Their oxygen comes from the oxygen gas of the air and the oxygen that is part of the carbon dioxide molecule. The former is used in respiration, and the latter becomes incorporated into organic compounds. Plant roots absorb nearly all the remaining elements in the form of mineral salts dissolved in soil water.

Plants remove from the soil not only those substances that they require, but others as well. Some plants become dangerous to animals because of the poisonous substances they accumulate in high quantity. Cattle, for example, suffer from selenium poisoning if they graze on plants growing in selenium-rich soil.

Animals inhale oxygen from the air, and they drink water; but they obtain nearly all other chemical compounds they need from their food. Unable to utilize carbon dioxide as plants do, animals get their carbon from the organic substances in the plants or animals that they eat. This is true also of nearly all the minerals that they require. The minerals are absorbed from the soil by plants and then reach the animals after the plants are eaten. Man benefits from agricultural research on the improvement of food crops through plant breeding.

WATER

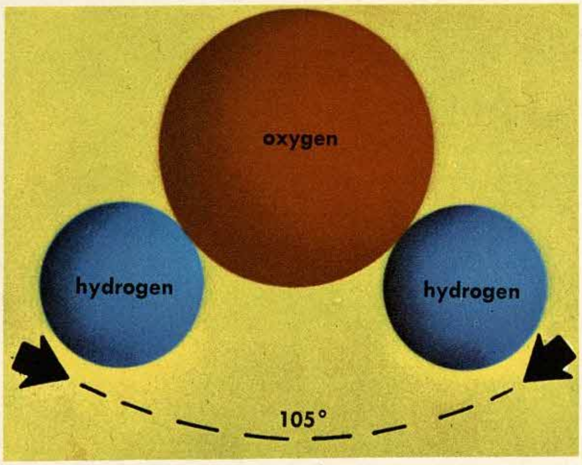
Although few details are known about the origin of life, it seems certain that it began in water. All active, living cells consist mostly of water; often they are more than 65 percent water. Only dormant structures like seeds or spores contain as little as 10 percent water.

The metabolism of all living things depends on a plentiful supply of water. Most species of animal live in water, and those that live on land carry a small private supply within their bodies in the form of blood or other body fluids.

Water has been called the universal solvent because it dissolves a wide variety of substances. Almost all the chemical reactions that occur in living things take place in water, and the reactants and products of these reactions are soluble in water. Minerals are dissolved in water before plants absorb them, and most substances must be dissolved in the water of the body fluids before they can be transported throughout the body. The whole series of chemical actions that are intimately related to the life of an organism —vegetable or animal—are associated with changes that take place in solution. It is known that the younger an animal, the richer it is in water content. It has been shown also that the fatter an animal, the smaller the percentage amount of water present.

Studies with heavy water and radioactive water have shown that exchange occurs between ingested water and metabolically derived water in the cells. Some water in cells is closely associated with proteins and other cellular constituents; it is known as bound water. Although some forms of life require little water, no life can exist without some water.

The problem of maintaining a proper water balance is different for animals that live in the desert, in moist air, in fresh water, in the sea, and in salt lakes. In many marine invertebrates, the total concentration of solutes in the blood is the same as that in the sea. In contrast, marine bony fish must continually excrete quantities of salts in order to keep their blood more dilute than the environment. Animals that colonize estuaries must keep their blood more concentrated than the water, often by active absorption of salts. Freshwater animals have mechanisms for excreting excess water, while land animals have mechanisms that limit evaporative loss and urinary loss of water.



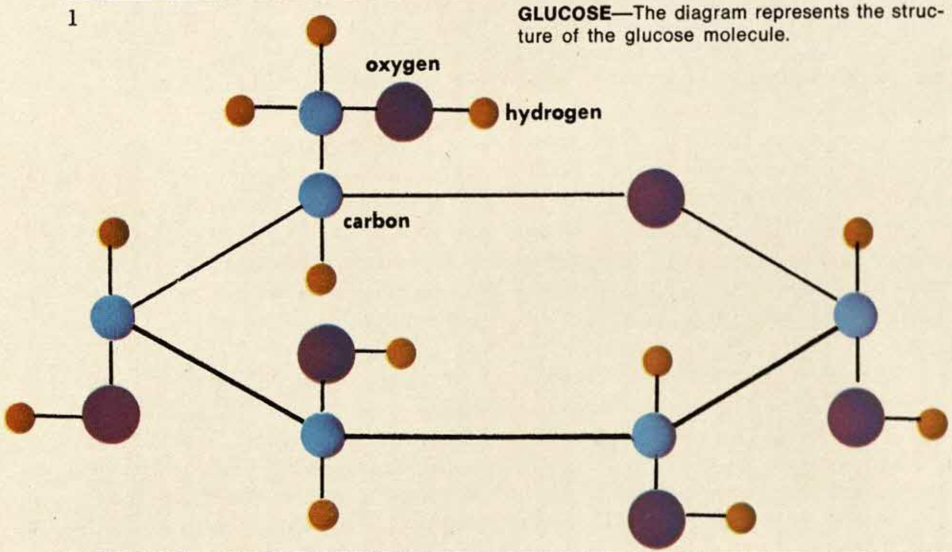
WATER — This illustration represents the water molecule. The angle between the two atoms of hydrogen and the oxygen atom is about 105°.

THE CHEMISTRY OF THE CELL—II

carbohydrates and lipids

A cell is not merely a sack of the several compounds that it absorbs from its environment. Once inside the cell, these compounds undergo several reactions that convert them into other compounds—usually more complex compounds that serve several functions within the cell. Some are the structural materials that form the basic framework of the cell: the several membranes of the cytoplasm, nucleus, ribosomes, other bodies within the cell, and the matrix of the cytoplasm; and, in plants and bacteria, the cell wall. Others are primarily energy sources that are stored until a supply of energy is needed; they are then oxidized in the energy-releasing process of respiration. A third function served by organic compounds is the catalysis or speeding up of reactions within the cell; these substances are enzymes.

1



GLUCOSE—The diagram represents the structure of the glucose molecule.

Three main groups of organic compounds perform these functions. They are carbohydrates, lipids, and proteins. All three groups contribute to the structure of the cell. Energy is obtained mostly from carbohydrates and lipids, rarely from proteins. All enzymes are proteins in whole or in part.

CARBOHYDRATES

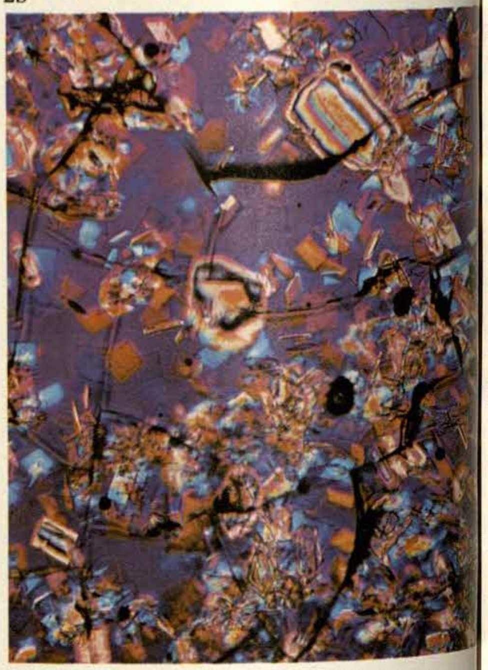
Carbohydrates received their name from the fact that they contain carbon, hydrogen, and oxygen, and that the hydrogen atoms and oxygen atoms exist in the same proportion that they do in water: 2:1.

The simplest of the carbohydrates are the simple sugars or monosaccharides. They are highly soluble in water and thus are transported readily throughout the organism.

The commonest of the monosaccharides is the sugar glucose, which has the formula $C_6H_{12}O_6$; another name for this sugar is dextrose. It is found in nearly all living cells and is readily oxidized in the process of respiration in living cells; thus, it is one of the most immediately available energy sources that a cell can use. Fructose, or fruit sugar, has the same formula as glucose, but the arrangement of the atoms within the molecule is different. It, too, can be oxidized readily. Galactose is a third monosaccharide with the same formula but with yet another configuration. Ribose ($C_5H_{10}O_5$) ordinarily is not used as an energy source but is present in larger, more complex molecules. One

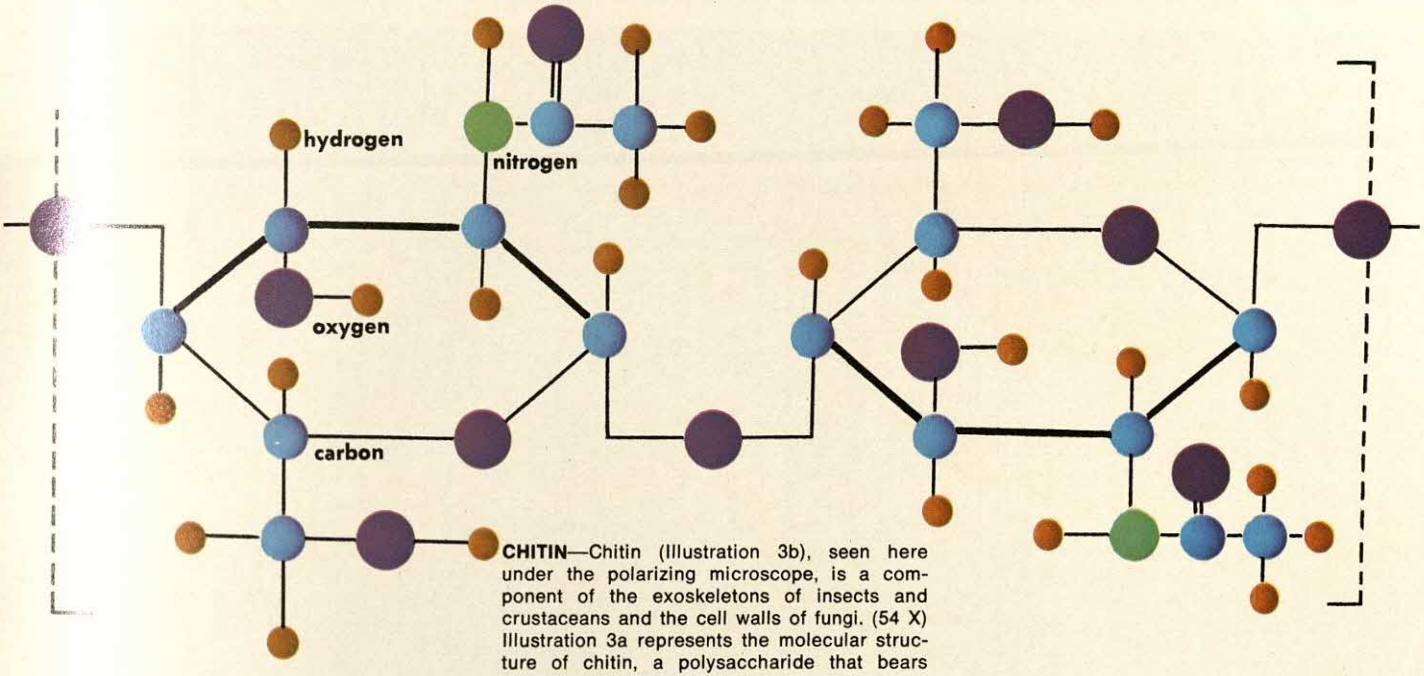
2a

2b



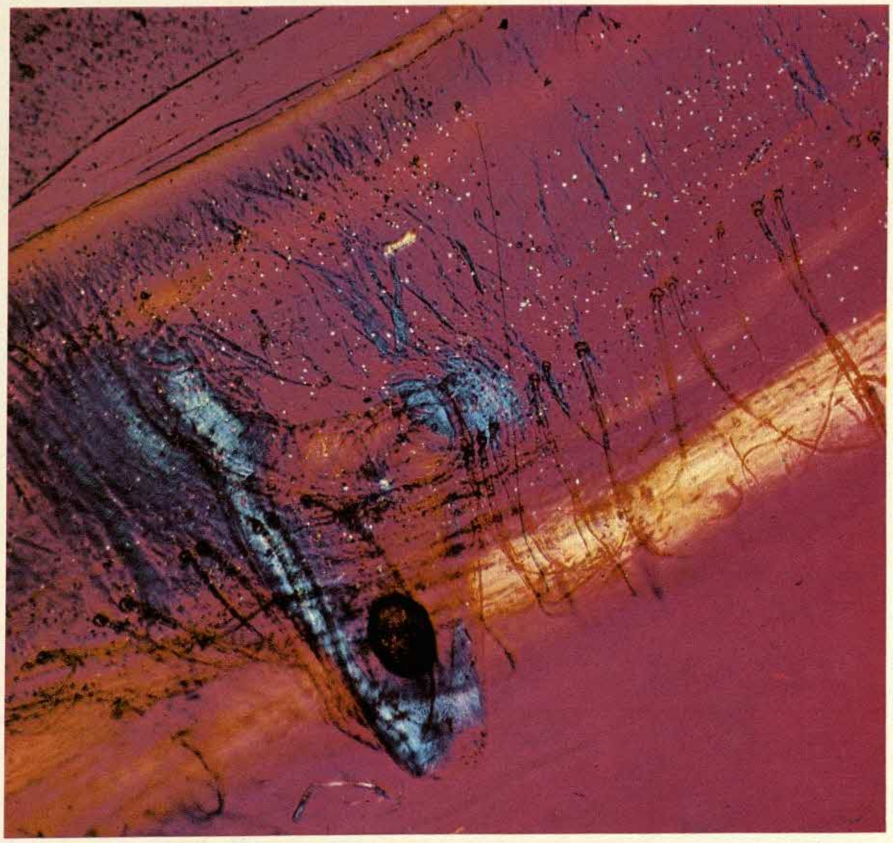
SUGARS—Glucose (Illustration 2a) has a feathery appearance when viewed under the polarizing microscope. (37 X) Sucrose (Illustration 2b), or common table sugar, has a different appearance in polarized light. (150 X)

3a



CHITIN—Chitin (Illustration 3b), seen here under the polarizing microscope, is a component of the exoskeletons of insects and crustaceans and the cell walls of fungi. (54 X) Illustration 3a represents the molecular structure of chitin, a polysaccharide that bears nitrogen-containing side groups.

3b

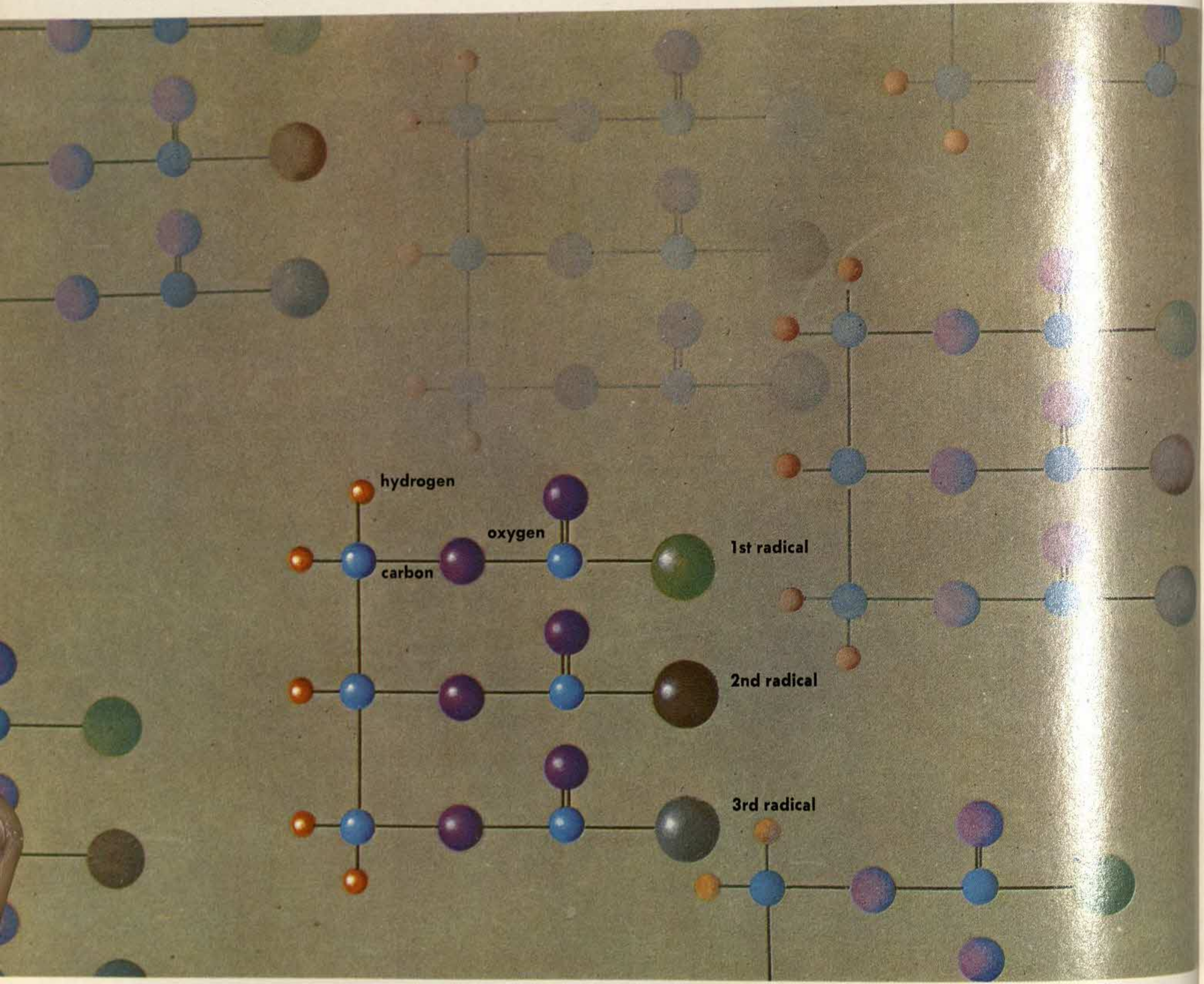


of these is adenosine triphosphate (ATP), which transfers energy within the cell. It is also part of ribonucleic acid (RNA), which controls in part the synthesis of enzymes within the cell. Deoxyribose ($C_5H_{10}O_4$) lacks one oxygen atom; this sugar is part of deoxyribonucleic acid (DNA), which is the genetic material of the cell.

Disaccharides are compounds formed by condensation reactions between two monosaccharides. Two hydrogen atoms and an oxygen atom are removed from the reactants and form a molecule of water. A common disaccharide is sucrose, or table sugar, which is formed from glucose and fructose:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{fructose}}{C_6H_{12}O_6} \rightarrow \underset{\text{sucrose}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O}$$

Lactose, or milk sugar, is the sugar found in milk; it is formed from glucose and galactose. Disaccharides are soluble in water. They cannot be oxidized in respiration, but they can be digested to their



FATS—A fat (triglyceride) is formed by the condensation of a glycerol molecule with three fatty acid molecules. In the illustration, the three fatty acids are indicated as the three radicals. They may all be the same fatty acid, or two may be alike, or all three different.

component monosaccharides, which can be oxidized.

$$\underset{\text{disaccharide}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} \rightarrow \underset{\text{monosaccharide}}{C_6H_{12}O_6} + \underset{\text{monosaccharide}}{C_6H_{12}O_6}$$

A larger molecule formed by a condensation reaction between two or more molecules is called a polymer. The reacting molecules are either identical or similar. Many natural polymers have large numbers of repeating units. Among them are the polysaccharides.

Polysaccharides are formed by the condensation of three or more monosaccharides arranged in a long chain. Those with only a few monosaccharide units are called oligosaccharides; most of them are soluble in water as are the monosaccharides and disaccharides. Because polysaccharides with high numbers of monosaccharide units—often 1,000 or more—are insoluble in water, they are not readily transported within the living organism, and thus they serve well either as structural components of the cell or as food reserves. Like disaccharides, polysaccharides are not oxidized, but they can be digested to monosaccharides that either can be oxidized in the same cell in which the digestion occurred, or can be transported to those parts of the organism where energy is needed.

Cellulose, starch, and glycogen are polysaccharides with glucose as the repeating unit. The glucose units form long chains that may be branched or unbranched, and in cellulose they are unbranched. Starch consists of a mixture of branched and unbranched chains.

Cellulose and starch are synthesized by plants. Cellulose is the main structural component of the plant cell wall, and it contributes to the rigidity of some plant parts. It is not readily digested by mammals, but it can be digested by some of the bacteria that live in their digestive systems. Cows and other ruminant animals receive much of their nutrition from the products of cellulose digestion by the bacteria that live in their specially modified stomachs. Human beings have cellulose-digesting bacteria in the large intestine; because little food is absorbed into the body from the large intestine, however, cellulose is of little nutritive value to human beings.

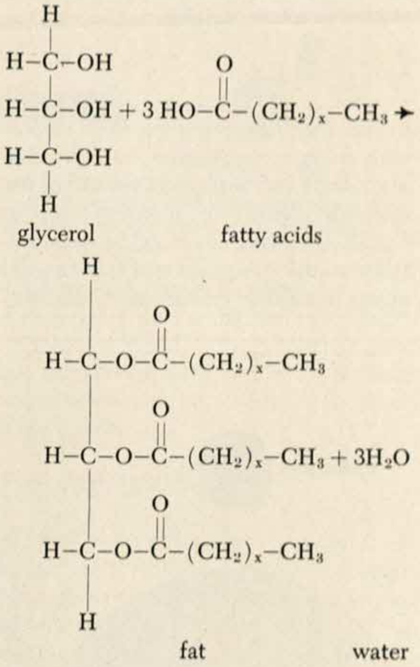
Many plants store their excess food in the form of starch, which can be digested readily to glucose, which then is respired with the release of energy. Because human beings and many animals can digest starch, they find cereal grains, potatoes, bananas, and other starch-rich plant parts highly acceptable foods.

Glycogen is called animal starch because it is similar chemically to starch and is found in animals but not in most plants. After a meal, glucose that has been absorbed by the small intestine is transported by the circulatory system to the liver, where the glucose is converted to glycogen and stored until it is needed. The glycogen is digested to glucose whenever the glucose level of the blood drops.

Chitin is a modified polysaccharide, each glucose unit of which bears a nitrogen-containing side chain. Chitin forms the hard exoskeletons of insects and crustaceans and the cell walls of fungi.

LIPIDS

Lipids include the fats and several fatlike substances. All contain carbon, hydrogen, and oxygen, but the oxygen content is very low. Most of them are insoluble in water. A fat molecule is formed by the condensation of three fatty acid molecules with glycerol, a polyalcohol:



$$\mathrm{H{-}CH(OH){-}CH(OH){-}CH(OH){-}H + 3\,HO{-}\overset{O}{\overset{\|}{C}}{-}(CH_2)_x{-}CH_3 \rightarrow H{-}C{-}O{-}\overset{O}{\overset{\|}{C}}{-}(CH_2)_x{-}CH_3 \ldots + 3H_2O}$$

The x in the preceding fatty acid formula is an even number, for fatty acids are synthesized by the addition of two-carbon units to the chain of carbon atoms. The three fatty acids contributing to the synthesis of a fat molecule may be the same, or they may be different. Digestion of fats produces glycerol and fatty acids.

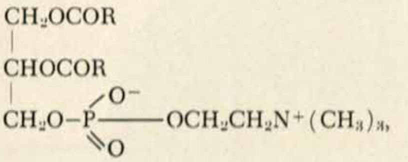
Saturated fatty acids are those having no double bonds between the carbon atoms. Unsaturated fatty acids have one or more double bonds; because of this the molecules have fewer hydrogen atoms than they otherwise might have. Stearic acid is a saturated fatty acid (*see* Structure a).

Oleic acid is the most widely distributed of all the fatty acids. Apparently it occurs to some extent in all oils and fats. Oleic acid is unsaturated (*see* Structure b).

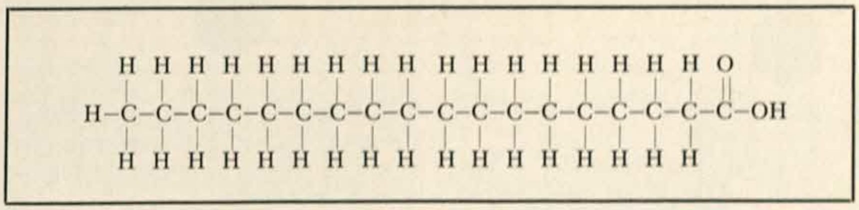
Acids with several double bonds are polyunsaturated acids.

Fats are a second type of reserve food stored by the body. The fats accumulate as globules in the cells of the adipose tissues that are distributed throughout much of the body.

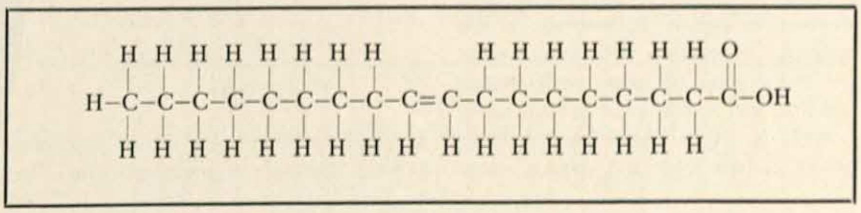
Phospholipids have a phosphate group in the place of one of the fatty acids, and the other groups may be attached to the phosphate group. One phospholipid, lecithin, is one of the structural components of the cell membranes, including the plasma membrane, the endoplasmic reticulum, the nuclear membrane, and the membranes of which mitochondria and chloroplasts are composed.



$$\begin{array}{l}\mathrm{CH_2OCOR}\\ |\\ \mathrm{CHOCOR}\\ |\\ \mathrm{CH_2O{-}P(O^-)(O){-}OCH_2CH_2N^+(CH_3)_3,}\end{array}$$



a



b

THE CHEMISTRY OF THE CELL—III

proteins, structural compounds

One of the most important groups of organic substances consists of the proteins and their related compounds. The role of those proteins that are enzymes—the catalysts that speed biochemical reactions in cells—is essential to life. Some proteins or similar compounds are hormones, and they, too, exercise a regulatory function in the body. Other proteins are structural compounds; they are one of the major components of the cellular membranes and other parts of the cell. Finally, the antibodies are proteins with an important function: defense against infectious disease.

Proteins are large molecules of high molecular weight; these molecules are polymers consisting of chains of variable numbers of amino acids—often a few hundred. In addition to carbon, hydrogen, and oxygen, all amino acids contain nitrogen, and a few have a little sulfur as well. Nearly all proteins, therefore, contain carbon, hydrogen, oxygen, nitrogen, and small amounts of sulfur. In addition, phosphorus and other elements are present in a few proteins.

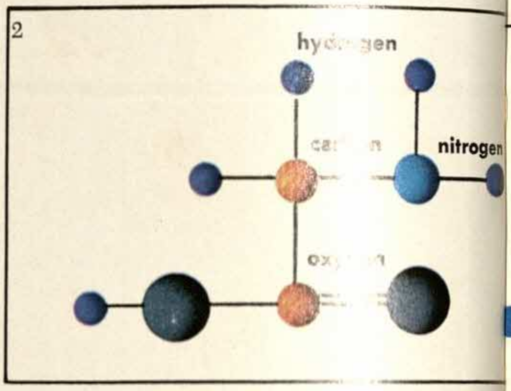
AMINO ACIDS

Amino acids, the repeating units of proteins, vary in composition, but all amino acids share two features. One end of the molecule consists of a carboxyl group (−COOH), which is an acid group. Adjacent to the carbon atom of the carboxyl group is another carbon atom, and this atom bears an amino group ($-NH_2$). The remaining part of the molecule varies and is indicated in structural formulas by an R, for radical:

$$NH_2-\overset{\displaystyle R}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-COOH$$

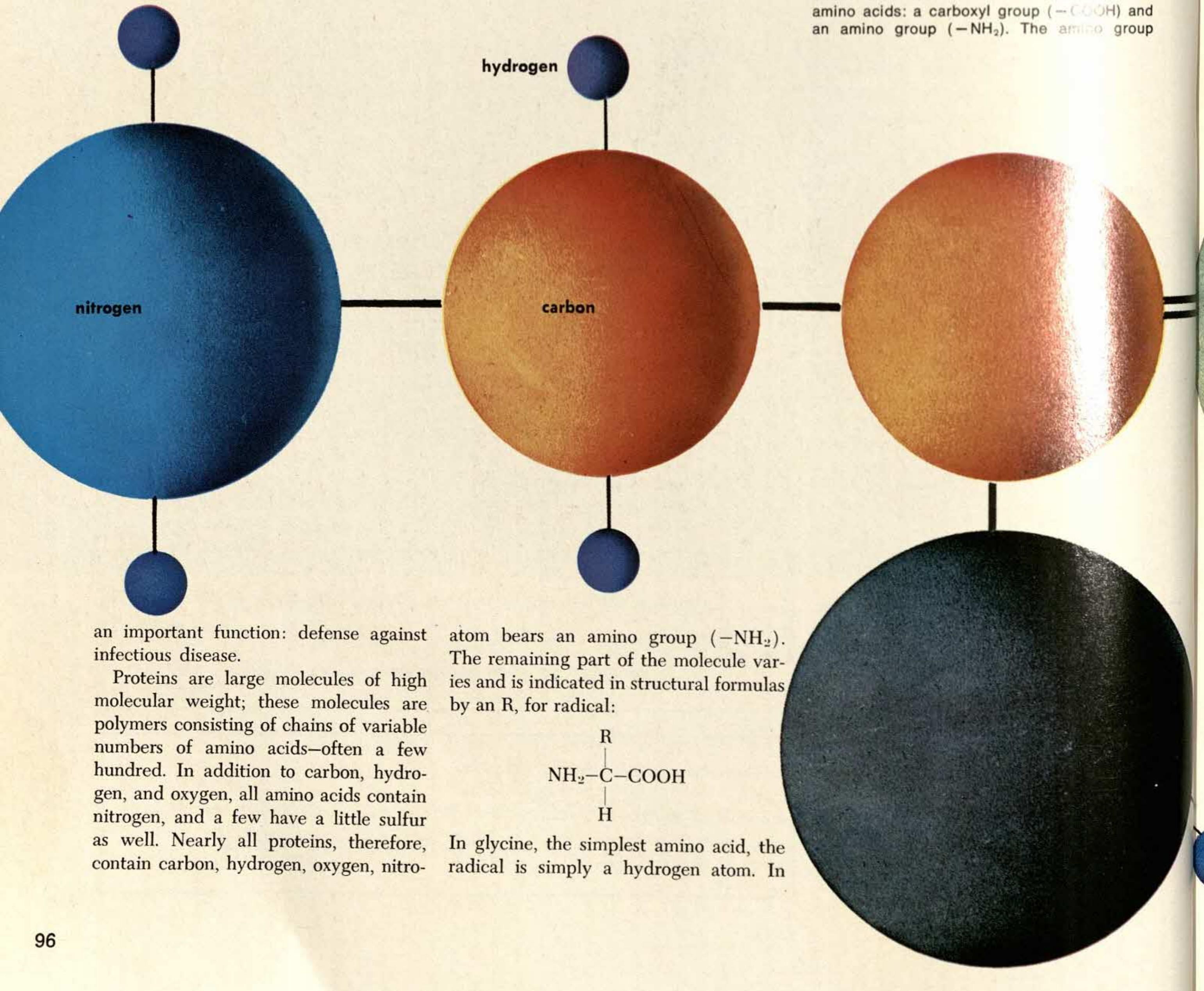
In glycine, the simplest amino acid, the radical is simply a hydrogen atom. In

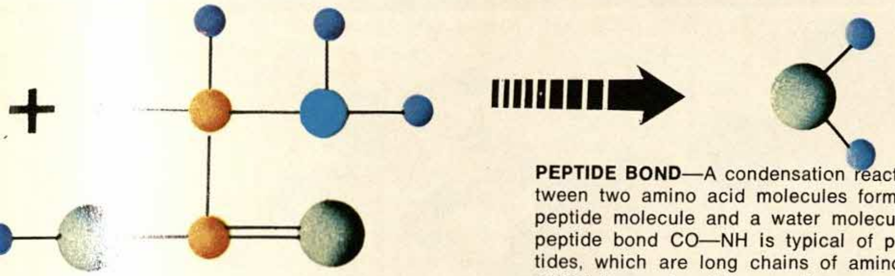
2



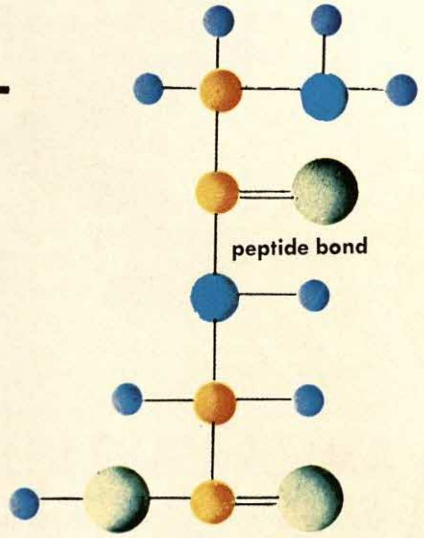
GLYCINE—The simplest naturally occurring amino acid has the features common to all amino acids: a carboxyl group (−COOH) and an amino group ($-NH_2$). The amino group

1





PEPTIDE BOND—A condensation reaction between two amino acid molecules forms a dipeptide molecule and a water molecule. The peptide bond CO—NH is typical of polypeptides, which are long chains of amino acids united by condensation reactions.

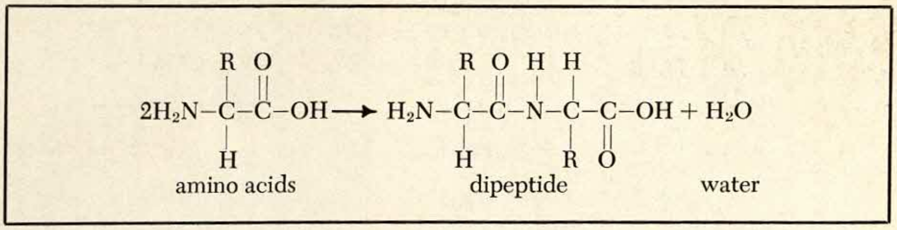


always is attached to the carbon atom adjacent to the carboxyl group. Other amino acids are larger, with chains of three or more carbon atoms.

other amino acids, it consists of a side chain of one or more carbon atoms. Two amino acids, cysteine and methionine, have sulfur in the side chain; and cystine, which is formed from two cysteine molecules, has two sulfur atoms in the center of the molecule. In some amino acids, the side chain may contain an additional carboxyl or amino group. In the formation of proteins, 20 naturally occurring amino acids are utilized by cells. After incorporation into proteins, some of these amino acids may be modified into other amino acids.

THE PEPTIDE BOND

A condensation reaction between two amino acid molecules occurs between the carboxyl group of the one molecule and the amino group of the other. As in many other condensations, a molecule of water is produced:



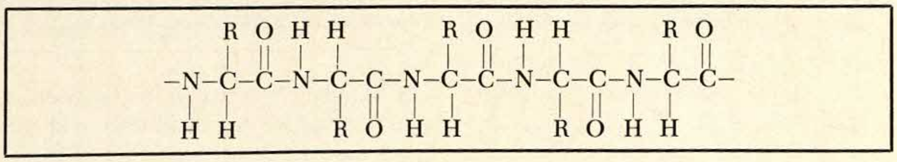
a

$$2H_2N-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH \longrightarrow H_2N-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R}{\overset{H}{C}}-\underset{O}{\underset{\|}{C}}-OH + H_2O$$

amino acids dipeptide water

The larger molecule formed from the two amino acids is a dipeptide, and the bond between the two amino acid units is a peptide bond.

Like an amino acid, a dipeptide has one amino group and one carboxyl group, both of which are capable of reacting with other groups. In this way, a long chain of amino acids can be linked together by peptide bonds formed in condensation reactions. Such a chain is called a polypeptide:

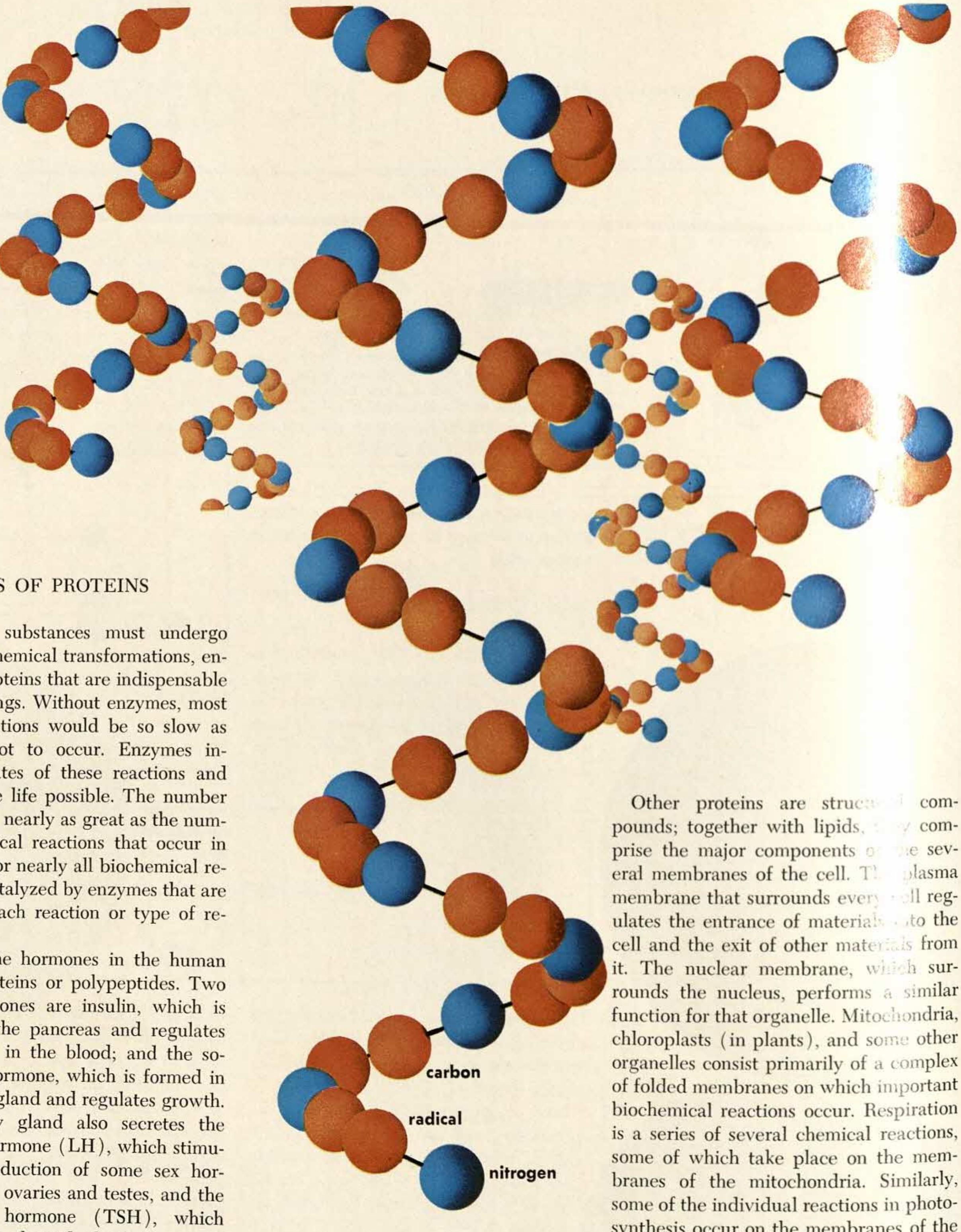


b

$$-\underset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R}{\overset{H}{C}}-\underset{O}{\underset{\|}{C}}-\underset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R}{\overset{H}{C}}-\underset{O}{\underset{\|}{C}}-\underset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-$$

PROTEINS

Some of the simpler proteins consist of only a single polypeptide, but many proteins are formed by the joining of a few polypeptides. This union is not by means of peptide bonds, but by chemical reactions between the reactive groups of the side chains. The sulfur-containing radicals and those with carboxyl and amino groups are important in this respect. Hemoglobin, the oxygen-transporting protein of the blood, consists of four polypeptides and four heme molecules; the latter are not proteins. The total complex is a conjugated protein.



POLYPEPTIDE CHAIN—In space, the polypeptide is coiled in a helix. The repeating —C—C—N— backbone of the molecule is shown but not the side groups.

FUNCTIONS OF PROTEINS

Because all substances must undergo continuous chemical transformations, enzymes are proteins that are indispensable for living things. Without enzymes, most of these reactions would be so slow as practically not to occur. Enzymes increase the rates of these reactions and thereby make life possible. The number of enzymes is nearly as great as the number of chemical reactions that occur in living cells, for nearly all biochemical reactions are catalyzed by enzymes that are specific for each reaction or type of reaction.

Some of the hormones in the human body are proteins or polypeptides. Two protein hormones are insulin, which is secreted by the pancreas and regulates glucose level in the blood; and the somatotropic hormone, which is formed in the pituitary gland and regulates growth. The pituitary gland also secretes the luteinizing hormone (LH), which stimulates the production of some sex hormones by the ovaries and testes, and the thyrotrophic hormone (TSH), which stimulates the thyroid gland to secrete thyroxin. Both LH and TSH are glycoproteins, proteins in chemical combination with polysaccharides. The adrenocorticotrophic hormone (ACTH) is a polypeptide produced by the pituitary gland; ACTH regulates the functioning of the cortex of the adrenal gland. Oxytocin and vasopressin are cyclic polypeptides with hormonal activity. The former stimulates the contraction of muscles of the uterus during childbirth, and the latter controls the permeability of membranes to water.

Other proteins are structural compounds; together with lipids, they comprise the major components of the several membranes of the cell. The plasma membrane that surrounds every cell regulates the entrance of materials into the cell and the exit of other materials from it. The nuclear membrane, which surrounds the nucleus, performs a similar function for that organelle. Mitochondria, chloroplasts (in plants), and some other organelles consist primarily of a complex of folded membranes on which important biochemical reactions occur. Respiration is a series of several chemical reactions, some of which take place on the membranes of the mitochondria. Similarly, some of the individual reactions in photosynthesis occur on the membranes of the chloroplast. Many of the proteins in the cellular membranes may have enzymatic as well as structural functions. Additional proteins are present in certain nonmembranous parts of the cell: chromosomes, ribosomes, and the matrix of the cytoplasm.

Some nonliving portions of some animals consist largely of proteins: hair, horns, hoofs, and fingernails.

CHROMOSOMES AND GENES | the treasure-houses of hereditary traits

In sexually reproducing species, each organism is formed by the union of two gametes, an egg from the female parent and a sperm from the male. These two cells transmit hereditary traits from parents to their offspring. The genetic (hereditary) material consists of genes that are located on elongated structures called chromosomes, and the chromosomes located in the nucleus of every cell of an individual. Each cell has a fixed number of chromosomes, half of which came from the female parent of the individual and half from the male parent. The number of chromosomes varies from one species to another. Some simple forms of life have a single set of genes and chromosomes during most of their life cycle.

MORPHOLOGY OF THE CHROMOSOMES

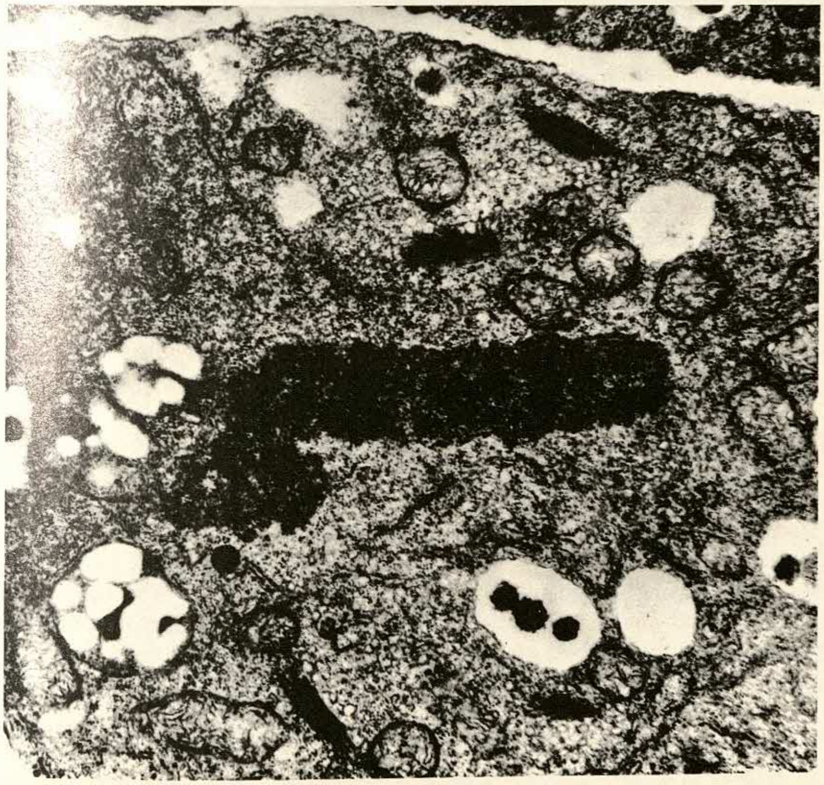
It is easiest to study the morphology of chromosomes when they are in metaphase or anaphase of mitosis; at this time they are short and thick and can be seen most clearly. During other phases of mitosis the chromosomes are too thin and elongated for effective examination.

During metaphase and anaphase the chromosomes have rodlike forms of various sizes (in man they measure from 1.64 to 9.12 μm). Chromosomes consist mostly of material that is easily colored with common biological stains, and so this material is called euchromatin. Somewhere along the length of each chromosome is a constriction known as the primary constriction, in which a special organelle—the centromere—is found. The primary constriction absorbs much less color than does euchromatin and so is said to be composed of heterochromatin. The centromere is the point at which the chromosomes are attached to the fibers of the central spindle, along which, during anaphase, they migrate toward the poles. The parts of a chromosome on either side of the centromere are its arms.

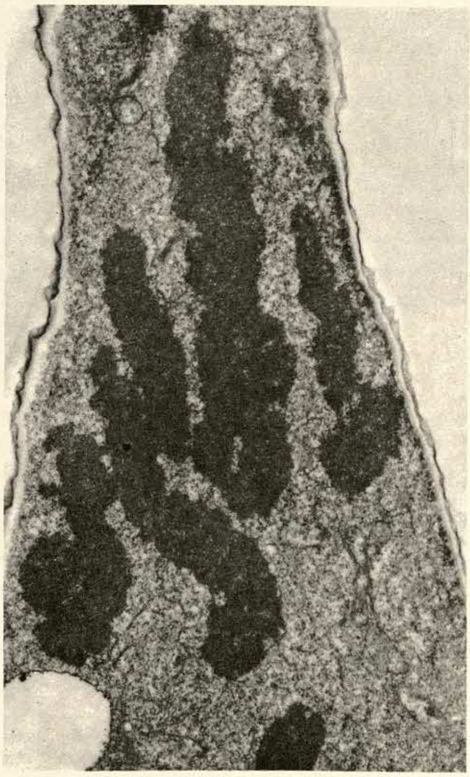
According to the positions of the centromeres, chromosomes can be divided into three categories: metacentric, subtelocentric, and telocentric. Chromosomes are metacentric when the centromere is in a median or paramedian

CHROMOSOMES UNDER THE ELECTRON MICROSCOPE—Chromosomes are clearly evident in these sections of plant cells as seen under the electron microscope. Illustration 1a shows a section of a *Haplopappus gracilis* cell. (27,000 X) The dark structure visible at the center is a subtelocentric chromosome in the form of a J. It consists of closely packed fibrils of nucleoprotein (DNA and histones) of about 100 Å in diameter. The DNA in these fibrils contains the genetic code. Illustration 1b shows chromosomes in mitotic metaphase in a cell in a stamen filament of *Tradescantia*. (17,000 X)

1a



1b



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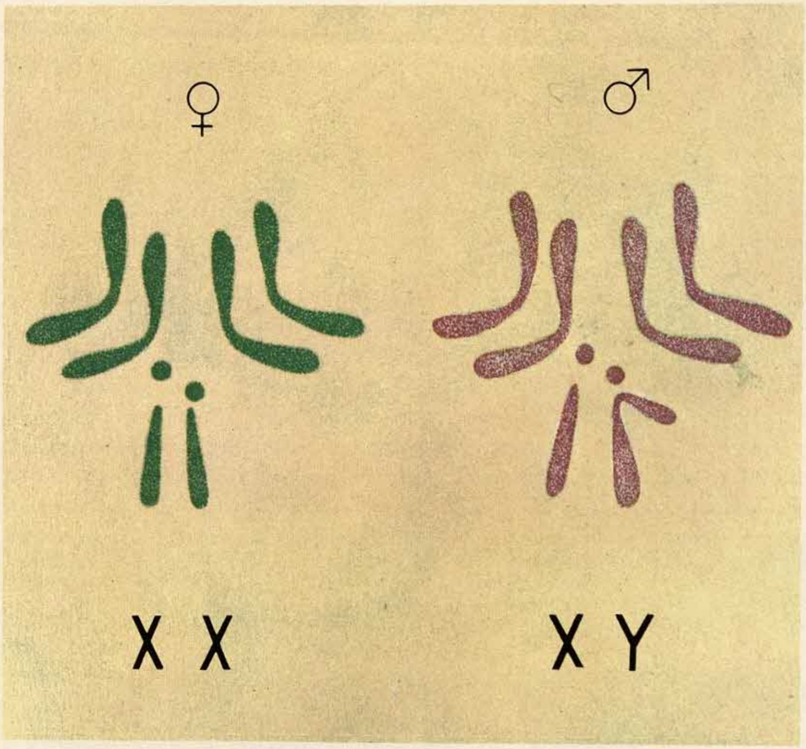

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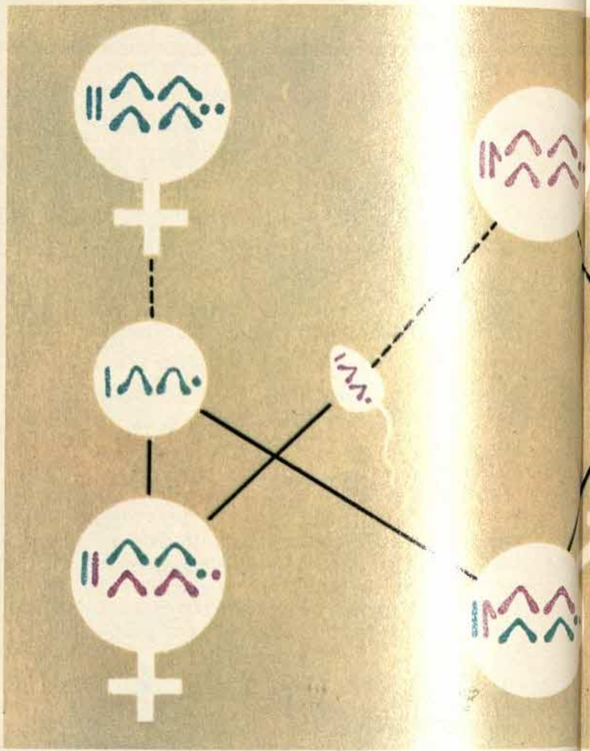

CHROMOSOMES OF THE FRUIT FLY—Each cell of the fruit fly *Drosophila melanogaster* has four pairs of chromosomes: two pairs of V-shaped, metacentric chromosomes, one pair of dot-shaped chromosomes, and one pair of sex chromosomes. In the female, the two sex chromosomes (XX) are similar and have a rod-shaped form. In the male, one is rod-shaped (X), while the other (Y) is J-shaped (Illustration 2).

DETERMINATION OF SEX—During the formation of gametes, the two sex chromosomes enter different gametes. All the eggs produced by the female parent contain an X chromosome; half of the sperms produced by the male parent contain an X chromosome, and half contain a Y chromosome. If an egg is fertilized by an X-bearing sperm, the off-

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position and the chromosome has a V or horseshoe shape because its arms are of equal or nearly equal length. It is subtelocentric when the centromere is in a subterminal position and the chromosome has the form of a hook or a J, wherein the arms are of very different lengths. A chromosome is telocentric when the centromere is at the end of the chromosome, which in this case has only one arm in the shape of a simple rod.

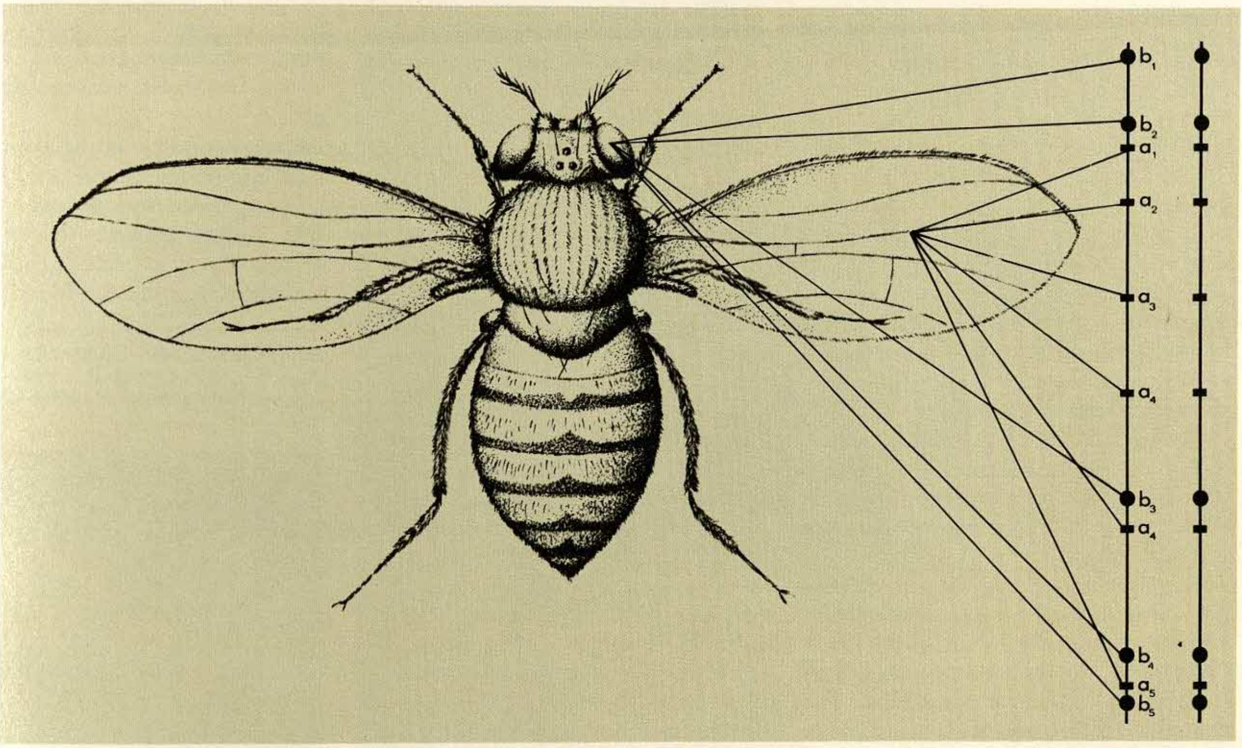
Often, in addition to the centromere, the chromosome has other constrictions, called secondary constrictions, at various points along the two arms. Occasionally one of these constrictions is located near one extremity of the chromosome and isolates a rounded portion called a satellite.

AUTOSOMES AND SEX CHROMOSOMES

The maternal and paternal chromosomes in each cell occur in pairs. The two members of a pair are called homologous chromosomes, and they are identical both in form and size. With one exception, the chromosomes form pairs that are the same in the cells of both sexes and are called autosomes. The sex chromosomes, however, are not always paired. Many species have two different sex chromosomes (X and Y) in one sex (called the heterogametic sex) and two like ones (XX) in the other sex (called the homogametic sex). In this case X and Y differ in shape and size. In the mammals (including man) and in many insects, females have an XX pair, and males have an X and a Y chromosome. In some insects (the squash bug, for instance), the females have two X chromosomes, and the males have an X but no Y. In butterflies, moths, birds, reptiles, and some

sp will have two X chromosomes and will be emale; if, instead, the sperm bears a Y ch osome, the offspring will have an X and a romosome and will be male (Illustration 3).

4



POSITION OF THE GENES—Genes—the elements that determine the inheritance of characteristics—are disposed on the chromosomes in a linear arrangement in positions (loci) that are identical in homologous chromosomes. Illustration 4 shows the arrangement of the genes that regulate the development of the wings and the eyes of *Drosophila*. Gene $\mathbf{a}_1$, for example, governs the form of the wing. Genes $\mathbf{b}_1$, $\mathbf{b}_2$, $\mathbf{b}_3$, and $\mathbf{b}_4$, together govern the color of the eyes.

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fishes and amphibians, the males have two X chromosomes, and the females have either an X and a Y or only one X.

THE GENES

Human beings have 46 chromosomes—22 pairs of autosomes and a pair of sex chromosomes. On these few chromosomes are thousands of genes, which are responsible for the transmission of thousands of hereditary traits from one generation to another. Genes are so small that they cannot be seen through a microscope, but the results of genetic experiments indicate that genes are arranged in linear fashion in the chromosome. The position of each gene is called its locus, and there is one gene at each locus. An analogy might be drawn between a chromosome and a string of pearls, in which each pearl represents a gene. Two homologous chromosomes are, therefore, comparable to two necklaces of equal length in which the pearls are perfectly paired.

THE GENETIC CODE

The major chemical components of chromosomes are large molecules: the nucleic acids (DNA and RNA) and proteins. Of these, DNA contains the genetic code, or hereditary message. What an organism is depends in large part on the chemical reactions that occur in its cells; because most of these reactions are controlled by enzymes, and because enzymes are proteins, the synthesis of proteins is extremely important. The genetic code in the DNA molecules regulates what enzymes are produced; in this way DNA affects many of the characteristics of the individual. Hair color and eye color are examples of traits that are controlled by DNA.

MITOSIS | the cell that multiplies by dividing

A favorite saying in biology is that cells multiply by dividing. In the process of cell division, two cells originate from a single parent cell that thereby loses its identity. Ordinarily, the two daughter cells are about half the size of the parent cell. After division (or even during it), the daughter cells begin to increase in size. When they reach the size of the parent cell, they may divide again. These alternate processes of division and growth of cells are responsible both for increase in numbers of individuals in populations of unicellular organisms and for growth of multicellular organisms.

The factors that control mitosis are not well understood. One factor is probably the surface-volume relationship. When a cell increases in size, its volume increases at a faster rate than does its surface area. This is true of any three-dimensional object; as it increases in size, the surface area increases as the square of the linear dimensions, and the volume increases as the cube of the linear dimensions. The materials that a cell needs must enter through its surface, and its waste products must leave through the surface. The rate at which these substances can move across the cell membrane is limited by its surface area, but the need of the cell for foods and other materials and its production of waste products are proportional to its volume. A certain size is reached, therefore, when the surface area is too small for the proper functioning of the cell. The same problems occur in the case of the nucleus (and its membrane) as it increases in size. These problems are alleviated when the cell and its nucleus divide in two. The relationship of the size of nucleus to that of the cytoplasm also may be important.

How the surface-volume relationship triggers cell division is not known. One hypothesis states that as the cell grows, it produces a substance that, when it reaches a certain concentration, stimulates cell division. In plant cells, the production of a wound hormone has been demonstrated. This substance, produced by wounded cells, initiates cell division in neighboring cells. In intact tissues, cells in a given area often divide simultaneously (or essentially so); this action suggests that a hormone produced by healthy tissues may coordinate cell divisions.

With the exception of those divisions that give rise to reproductive cells, cell divisions produce two daughter cells that have identical genetic material. They are identical with their parent cells in this respect. The genetic material is confined to the chromosomes of the nucleus, and in a single cycle of cell division, each chromosome divides, producing two identical chromosomes; one of each of these pairs goes to each daughter cell.

The division of the nucleus is known as mitosis, and the division of the cytoplasm is known as cytokinesis. The process of mitosis is very exact, dividing the genetic material precisely between the two daughter cells. In most cases, the cytoplasm divides approximately in half, and each daughter cell receives about half of the mitochondria, ribosomes, and other cytoplasmic organelles; occasionally, the division is far from being equal.

For convenience, mitosis usually is discussed in four phases: prophase, metaphase, anaphase, and telophase. Actually, these phases merge gradually one into the other, and there is no sharp dividing line between them. A nucleus that is not dividing is in interphase.

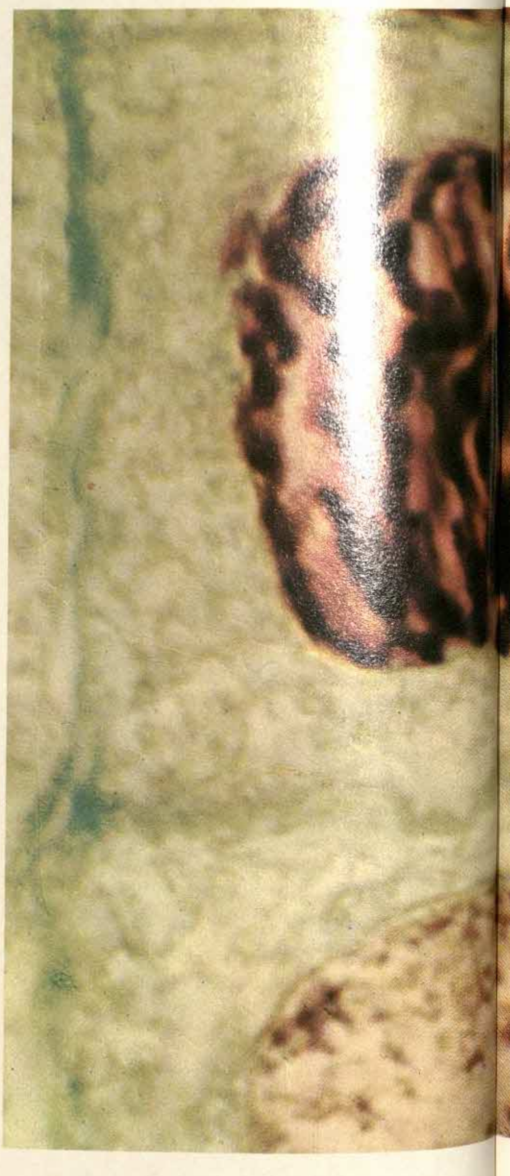
INTERPHASE

During interphase, the nucleus is usually spherical, but it may be somewhat distorted by its confinement in a small place such as a thin layer of cytoplasm or a long, narrow cell. The nucleus, which is bounded by a nuclear membrane, contains the chromosomes, which are so long and thin that under the microscope they resemble fine threads. Tangled in the nucleus, they are difficult to distinguish. Usually there is at least one nucleolus, a small spherical body, or there may be several.

The genetic material, deoxyribonucleic acid (DNA), is contained in the chromosomes. The precise composition of DNA varies from one part of a chromosome to another part and from one chromosome to another. The total DNA in all the chromosomes of a single cell contains the genetic information for carrying out all the metabolic reactions of the organism.

Late in interphase, before any visible signs of division can be seen in cells examined under a light microscope, the DNA replicates itself. The replication is very precise, each DNA molecule forming an exact replicate of itself. Just prior

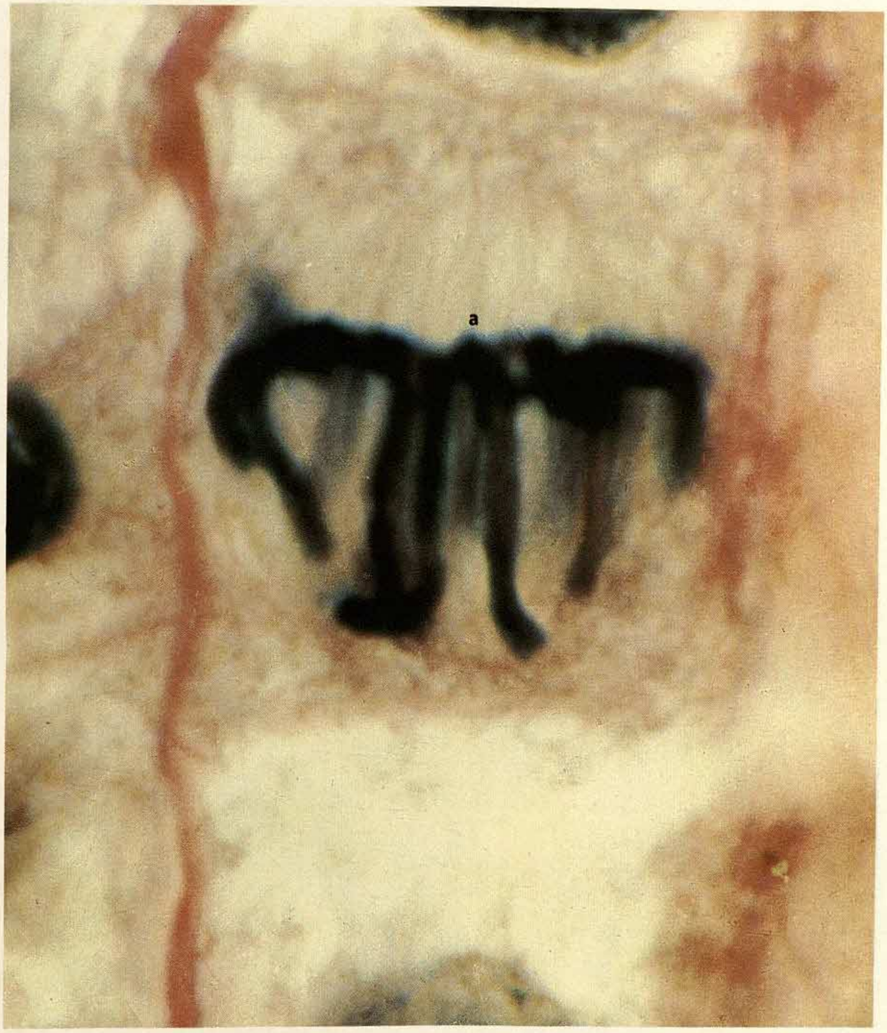
PROPHASE IN AN ONION CELL—The chromosomes have shortened and thickened only slightly. In this stage each chromosome con-



to mitosis, then, the genetic material of the cell is duplicated.

PROPHASE

sists of two chromatids spiraled around each other. (1,000 X) Each chromatid contains a complete set of DNA for that chromosome.



METAPHASE IN AN ONION CELL—The chromosomes are arranged on the metaphase plate. The very slender fibers of the spindle **a** that join the two poles of the cell are evident. (1,300 X) At this stage, the chromosomes are well-separated strands.

During prophase the chromosomes become shorter and thicker. As prophase proceeds, the chromosomes appear clearer, and it is evident that each consists of two long threads, or chromatids, that are wound around each other in spiral fashion. Each chromatid contains one complete set of DNA for that chromosome. The two chromatids are united at only one point along their length; this point is called the centromere. During prophase the nuclear membrane and the nucleoli break down and disappear. Fine fibers called spindle fibers begin to appear at opposite ends, or poles, of the cell. As the nucleolus disappears, DNA and certain proteins, along with RNA, plus other nucleolar constituents—such as alkaline phosphatase, phospholipids, and zinc—are found in the chromosomes.

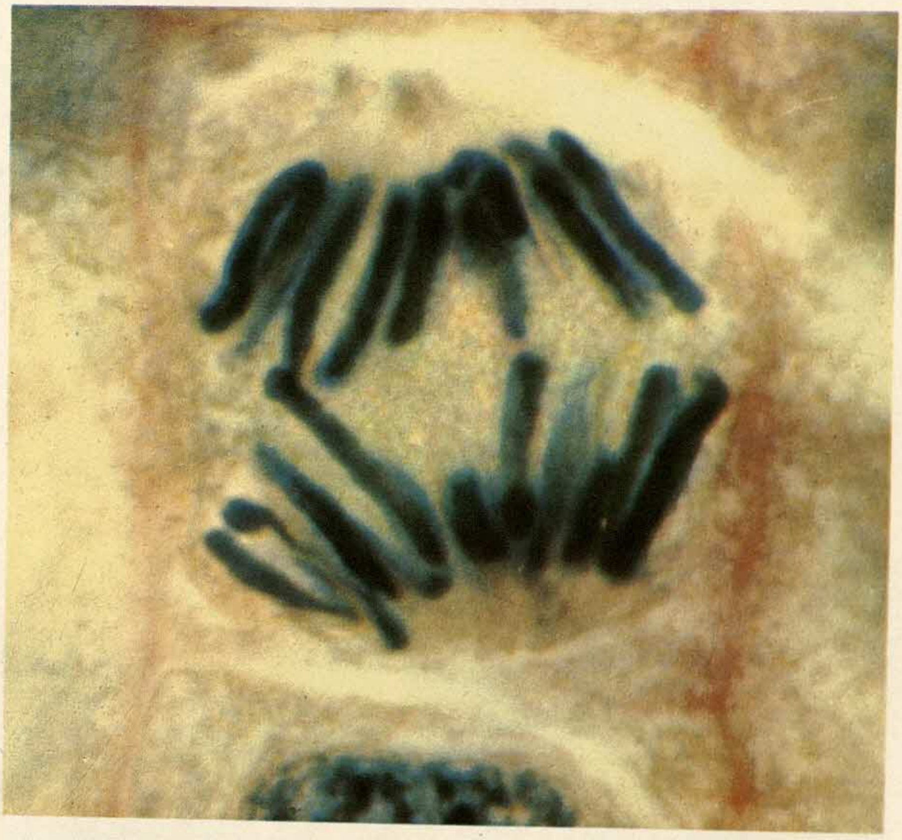
In animal cells, the spindle fibers radiate from small bodies called centrioles. In plant cells, no distinct structures can be seen, but the corresponding areas in the cytoplasm are called polar caps.

METAPHASE

When the spindle fibers have formed, they comprise a spindle-shaped body; some of them extend from pole to pole. Others extend from one pole or the other to the centromere of a chromosome. By means of these shorter spindle fibers, each chromatid of a metaphase chromosome is attached to opposite p s of the cell.

ANAPHASE

During anaphase the two chromat
each chromosome separate from
other and move to opposite poles
cell. To the eye, they appear to be
by the shortening of their spindle



ANAPHASE IN AN ONION CELL—The chromosomes are moving toward the poles of the spindle. The chromosomes moving toward one pole are identical to those moving toward the opposite pole. The individual chromosomes are short and thick and are easily distinguished. (1,700 X)

but the exact mechanism of movement is not known. After separating, each chromatid is called a chromosome. Because identical chromosomes move away from each other, the set going to each pole contains a complete set of DNA.

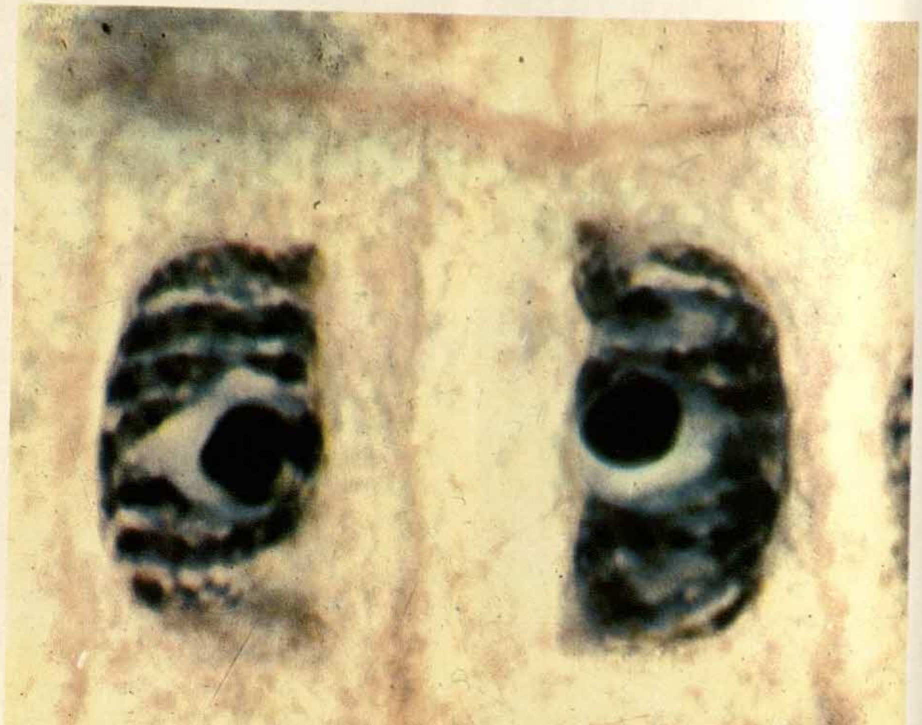
TELOPHASE

When the chromosomes reach the opposite poles, a nuclear membrane forms around each set. The nucleoli reappear in the new nuclei, and the chromosomes again become longer and thicker.

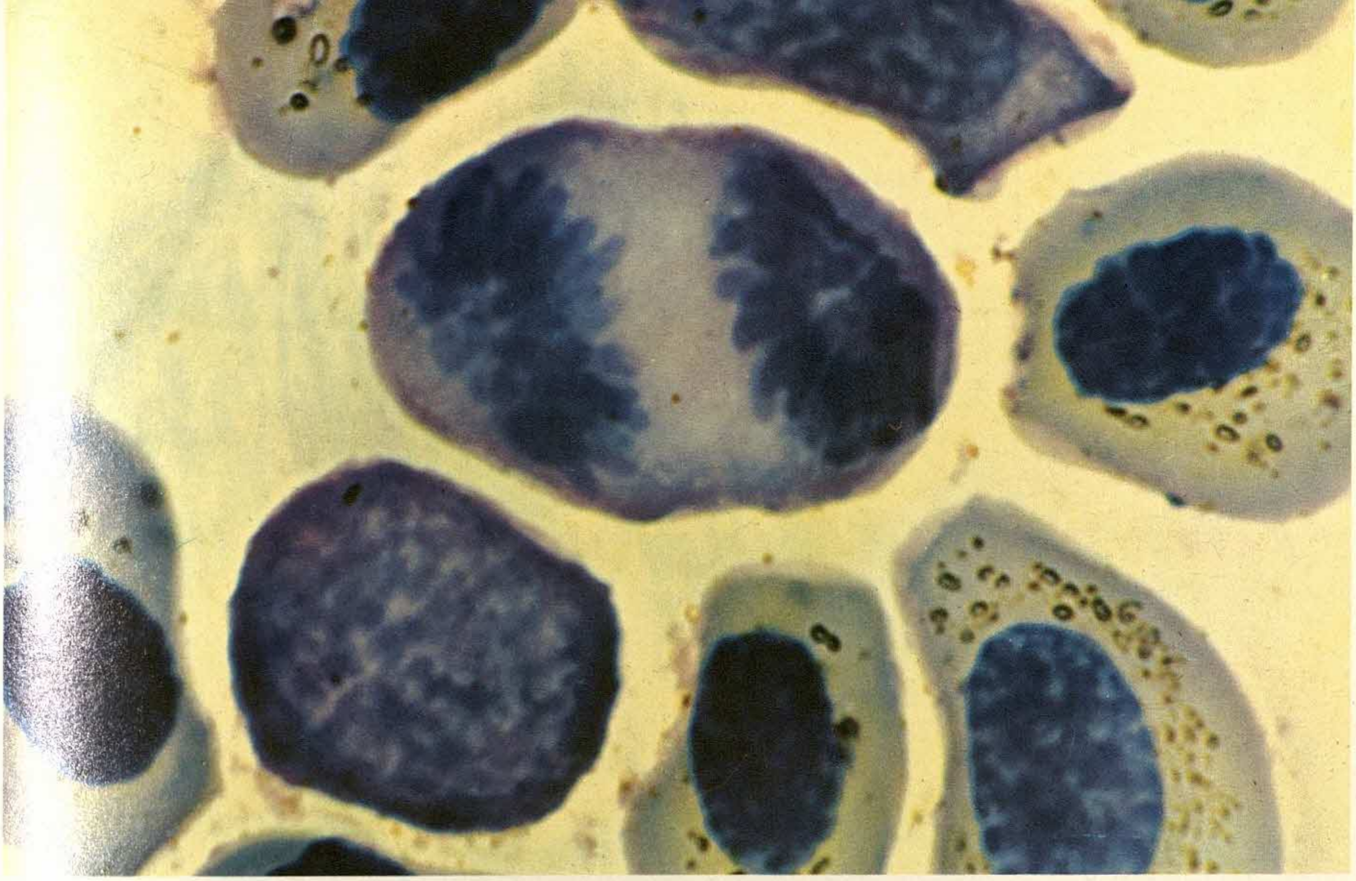
Cytokinesis, which completes cell division, usually begins during telophase. In animal cells, the cytoplasm pinches in two, forming two new cells. In plant cells, the long spindle fibers shorten toward the center of the cell and form a cell plate that divides the cytoplasm of the parent cell. The cell walls of the two new daughter cells form on this cell plate.

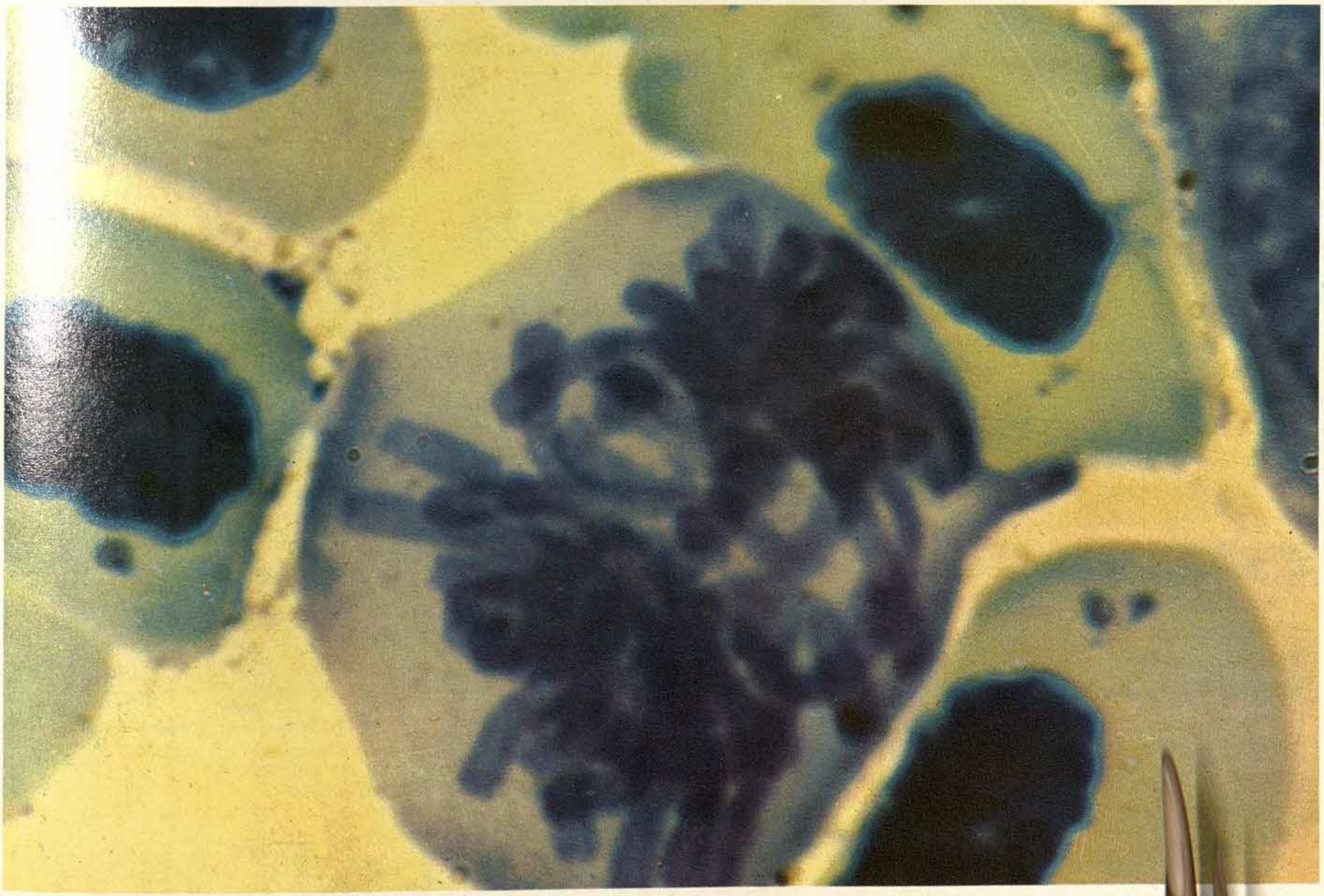
DAUGHTER CELLS

At the completion of mitosis, the nuclei of the daughter cells are genetically identical with each other and with the nucleus of the parent cell. Mitosis insures that every cell of an individual (other than its gametes) has the same genetic constitution.



TELOPHASE IN AN ONION CELL—The chromosomes begin to lengthen as two new nuclei begin to form. A cell plate divides the parent cell into two cells. (1,300 X)





ANAPHASE IN A CELL OF TRITON—The chromosomes (at top) are arranged at the two poles of the spindle in this late stage of anaphase. (1,700 X)

PROPHASE IN A CELL OF TRIT[illegible]—[illegible]he chromosomes (at bottom) are arran[illegible]d [illegible] quite a disorderly manner, but they a[illegible]lr[illegible]dy distinguishable. (1,700 X)

MEIOSIS | reduction of the number of chromosomes

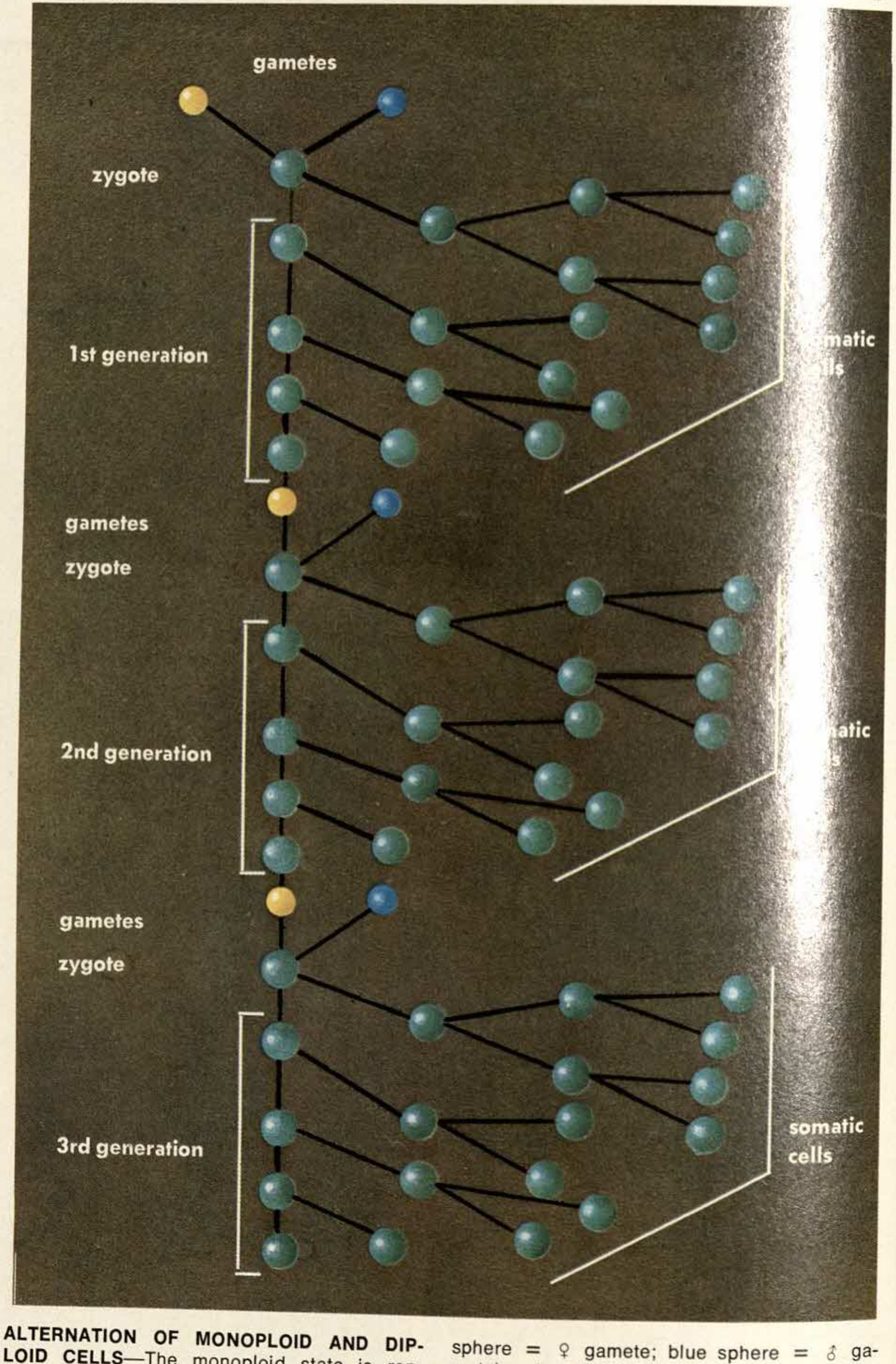
Sexual reproduction involves, of course, two parents: a male and a female. Even in those species in which only one individual may be involved—including many plant species and some animal species—that individual usually has the sex organs of both sexes.

In animals, the sex organs of males are the testes (testis, singular), which produce gametes, or sex cells, called sperms or spermatozoa. The sex organs of female animals, the ovaries, produce gametes called eggs or ova (ovum, singular). Fertilization is the fusion of one sperm with one egg. The fertilized egg, or zygote, is the first cell in the life of a new individual.

The zygote undergoes a mitotic cell division, forming a two-celled embryo. The two cells divide, forming four cells, the four form eight, and so forth. An adult organism is the result of repeated mitotic cell divisions that can be traced back to the original cell—the zygote. The many cells of the adult are differentiated into many tissues and organs. Most of the latter—including heart, lungs, muscles, brain, and many others—are somatic organs; their proper functioning is necessary for the life of the individual. One set of organs, the ovaries and testes, are the reproductive organs, and these are essential for reproduction of all of the groups of higher animals and some of the lower animals as well. Plants also have sexual organs, but their names vary among the different groups of plants.

Every species has a characteristic number of chromosomes per cell—a number that does not change from generation to generation. Because each generation of sexually reproducing organisms originates by the fusing of cells from two individuals of the preceding generation, the chromosome number would increase with each succeeding generation unless some mechanism prevented this. Such a mechanism is *meiosis*, a type of nuclear division that is present at one point in

1



ALTERNATION OF MONOPLOID AND DIPLOID CELLS—The monoploid state is represented by the smaller cells, and the diploid state by the larger ones. The gametes (yellow sphere = ♀ gamete; blue sphere = ♂ gamete) unite, forming the diploid zygote. Gametes are formed from diploid cells of the adult.

the life cycle of all sexually reproducing species. In animals, the sperms and eggs are produced by meiotic divisions.

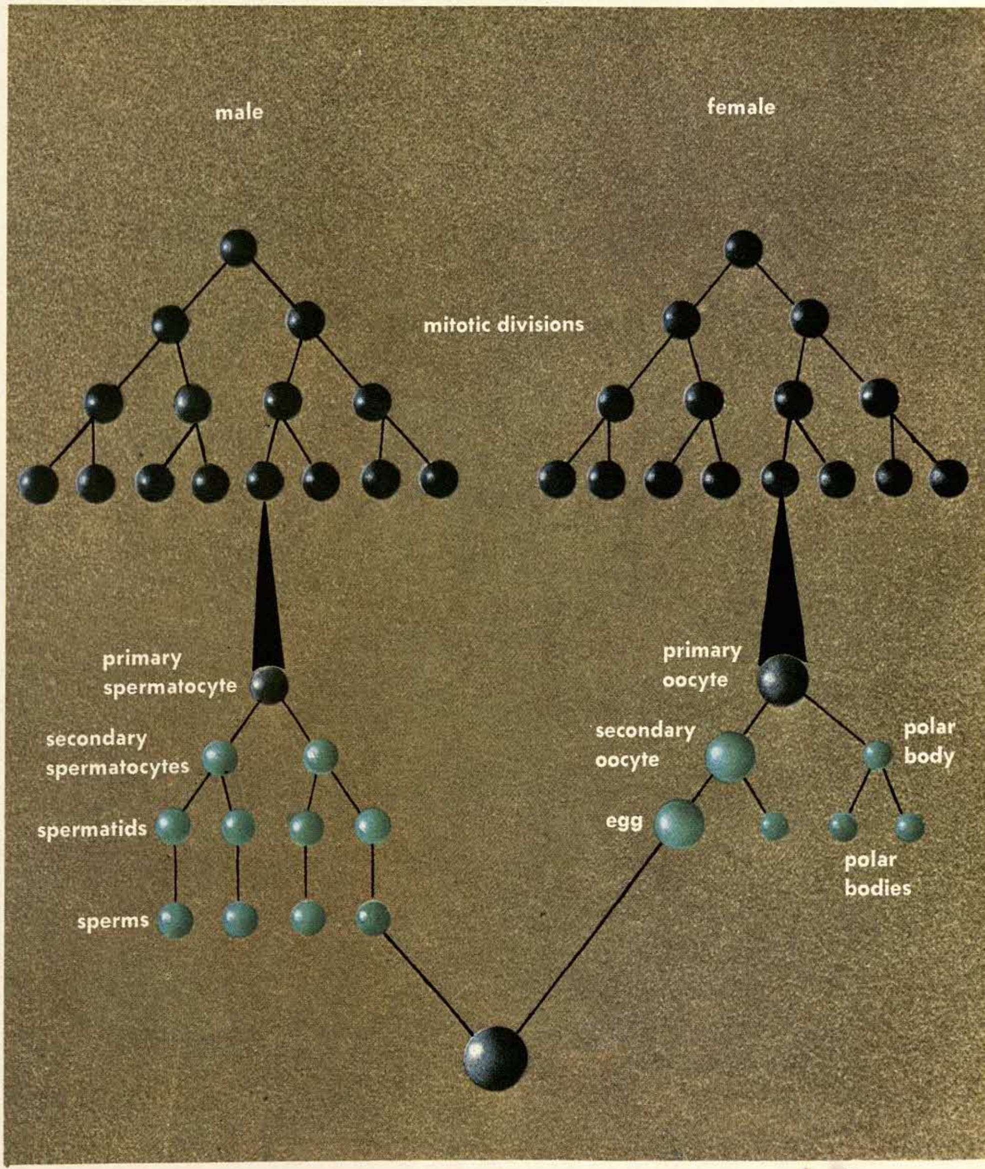
Meiosis consists of two nuclear divisions (usually accompanied by two divisions of the cell). One nucleus divides and forms two and the two divide, forming four. Because the chromosomes present in the original nucleus replicate themselves only prior to the first division and not between the two divisions, each of the four resulting nuclei has half the number of chromosomes that the original nucleus had.

The chromosomes of somatic cells occur in pairs, and the cells are said to be diploid. The sperms and gametes possess one member of each pair of chromosomes; they are called monoploid (or haploid). When a sperm fertilizes an egg the diploid number is restored. The alternation of meiosis and fertilization keeps the chromosome numbers constant from generation to generation.

Meiosis has an additional significance: half of the chromosomes in any somatic cell of an individual are derived from its paternal parent and half from its maternal parent. Although each gamete contains half of these chromosomes, the distribution of the chromosomes to the gametes is not affected by maternal or paternal derivation. If, for example, an individual has a pair of chromosomes **A** and **A′** derived from maternal and paternal parents, respectively, and another pair of chromosomes **B** and **B′** similarly derived, then the diploid cells of the individual all have the chromosomes **A, A′, B,** and **B′**. With two pairs of chromosomes, four possible combinations are possible in the gametes. Some gametes will have **A** and **B**, some **A** and **B′**, some **A′** and **B**, and some **A′** and **B′**. Most organisms have more than two pairs of chromosomes, and therefore have correspondingly more possible combinations of chromosomes in their gametes. In humans, who have 23 pairs of chromosomes, the number of possible combinations is 2^{23} or 8,388,608. This number is made even larger by a crossing-over, in which chromosomes exchange parts.

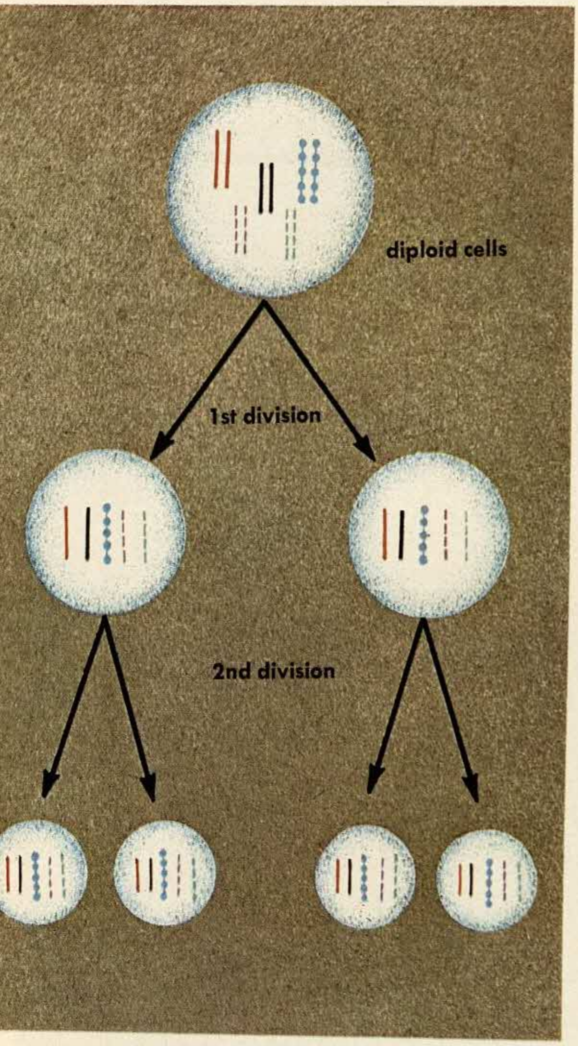
Variations like this in the gametes of both parents permit a great deal genetic variation in the offspring. T a survival value for a species, b s whenever the environment change e are likely to be at least a few indi s

2



MATURATION OF GAMETES—Mitotic divisions produce a large supply of diploid cells (shown in black), primary spermatocytes, and primary oocytes. These cells undergo eiosis, or reduction division, and their produ s a e shown in green.

3



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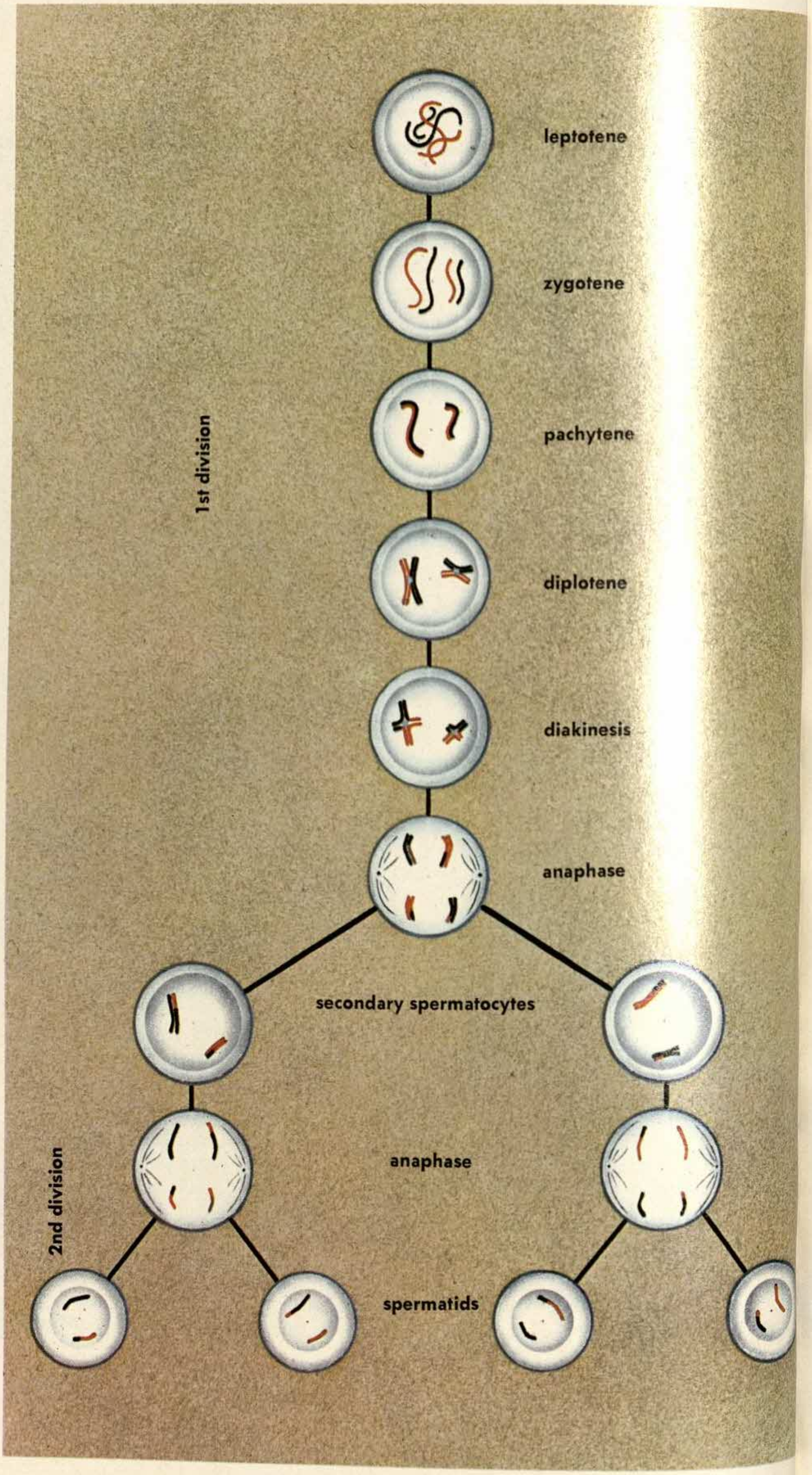

MEIOSIS—When a diploid cell with 10 chromosomes divides by meiosis, each of the two daughter cells of the first division receive five chromosomes, each consisting of two chromatids. The second division produces four cells with five chromosomes (Illustration 3).

SPERMATOGENESIS—Prophase of the first division is divided into several steps (Illustration 4). Unlike the prophase of mitosis, here the maternal and paternal chromosomes pair with each other. These chromosomes separate from each other at the first division and produce unlike cells.

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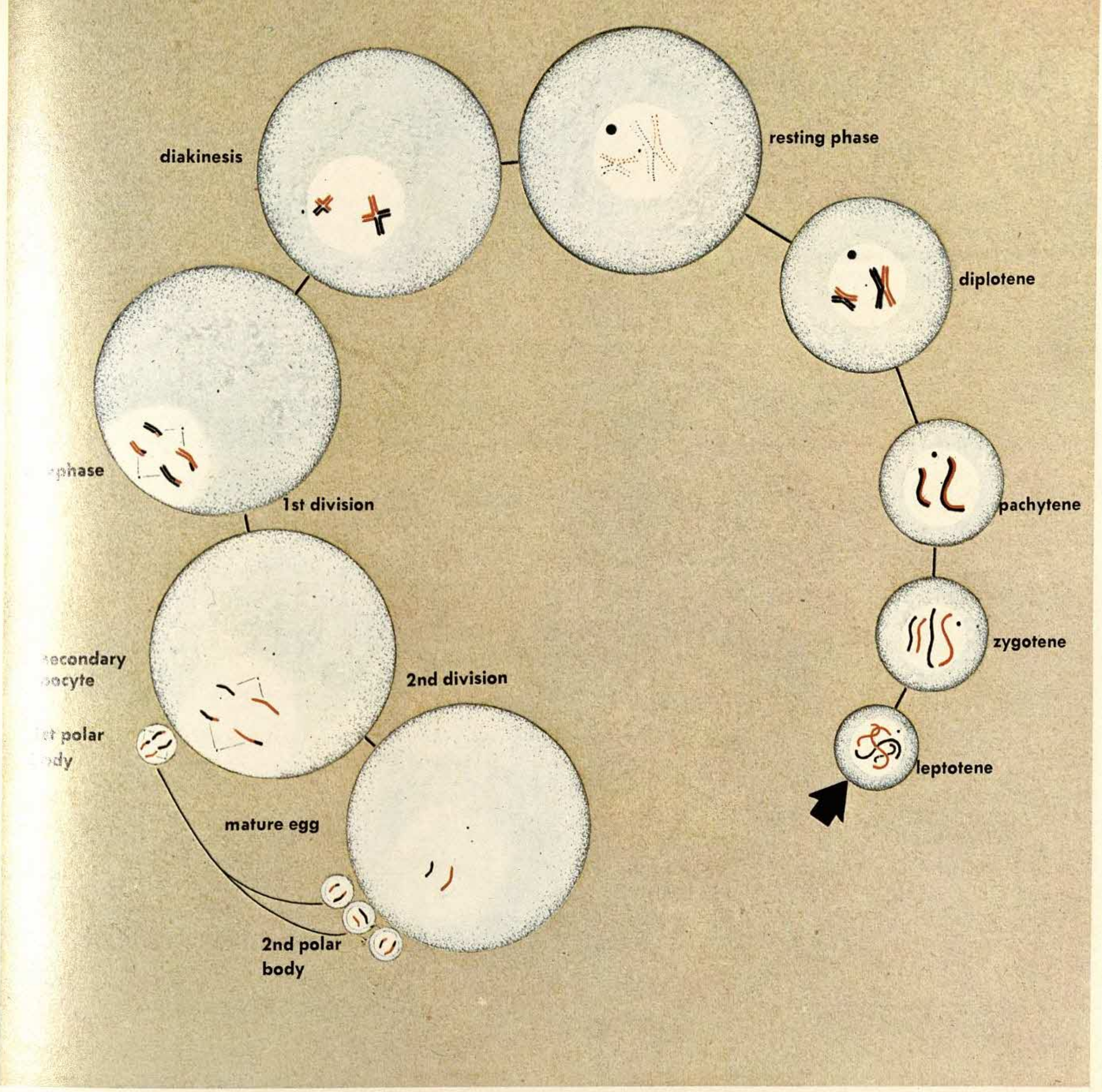
able to adapt to the new conditions and perpetuate the species. Asexual reproduction, which involves only mitosis, does not produce such great variations. It is not surprising, then, that nearly all species of plants and animals can reproduce sexually.

Spermatogenesis, the production of



OOGENESIS—This is the process of maturation of the female gamete, which also consists of two successive divisions. Only one resulting cell, the egg, is fertile. Three infertile polar bodies are formed. The production of eggs from oocytes occurs in the ovary.

sperms from spermatocytes, occurs in the testes. Primary spermatocytes are diploid cells. In the first division of meiosis, each primary spermatocyte produces two secondary spermatocytes, and these divide into four monoploid spermatids. The spermatids are spherical at first, but each one matures into a sperm cell by becoming more streamlined in shape and developing a thin tail. When introduced into the female reproductive tract, the sperms swim toward the egg. In most animals, including man, millions of sperms are produced simultaneously in the testes.

Oogenesis, the production of eggs from oocytes, occurs in the ovary. A primary oocyte, which is diploid, undergoes meiotic divisions that produce cells of unequal size. The first division produces a secondary oocyte, which is about the same size as the primary oocyte, and a very small polar cell. In the second division, the secondary oocyte produces an egg that is about the same size as the secondary oocyte, and a small polar cell. The first polar cell divides into two small polar cells. The result is four monoploid cells, an egg, and three polar cells. Of these, only the egg is functional. In some animals, including humans, the first polar cell may not even undergo the second division. The number of eggs produced by a female at any one time varies a great deal with the species. In fishes the number is often large—thousands or even millions. In mammals and birds the number often is low—usually not more than a dozen and often fewer than a dozen. In humans, one egg is produced every four weeks, and the two ovaries alternate in producing the eggs.

GENETICS AND MENDEL'S LAWS

how characters are transmitted

"Like begets like" is an old saying reflecting the common observation that parents and children usually resemble each other more than do distantly related individuals. Genetics is the science of heredity; it seeks to explain not only why offspring resemble their parents but also why they differ in some ways. During the course of history, men must often have pondered this problem, but not until the middle of the nineteenth century did Gregor Mendel, an Augustinian monk in Brünn (Brno, Czechoslovakia) perform experiments that clearly established several basic laws of heredity. His results

MENDEL'S LAW OF SEGREGATION—If a white mouse is crossed with a black one, the first generation of offspring consists of gray hybrids. If these hybrids are crossed with each other, their offspring consist of about 25 percent black mice, 50 percent gray mice, and 25 percent white mice. Thus, the traits of the parental generation (white and black), which seem to disappear in the F_1, reappear in the F_2. The gray mice of the F_1 generation each carry one gene for black and one for white. When the F_1 mice form gametes, these genes segregate at random, with some F_2 mice receiving two genes for white, some receiving one for white and one for black, and others receiving two for black. In this case, neither white nor black color is dominant to the other; this condition is called incomplete dominance.

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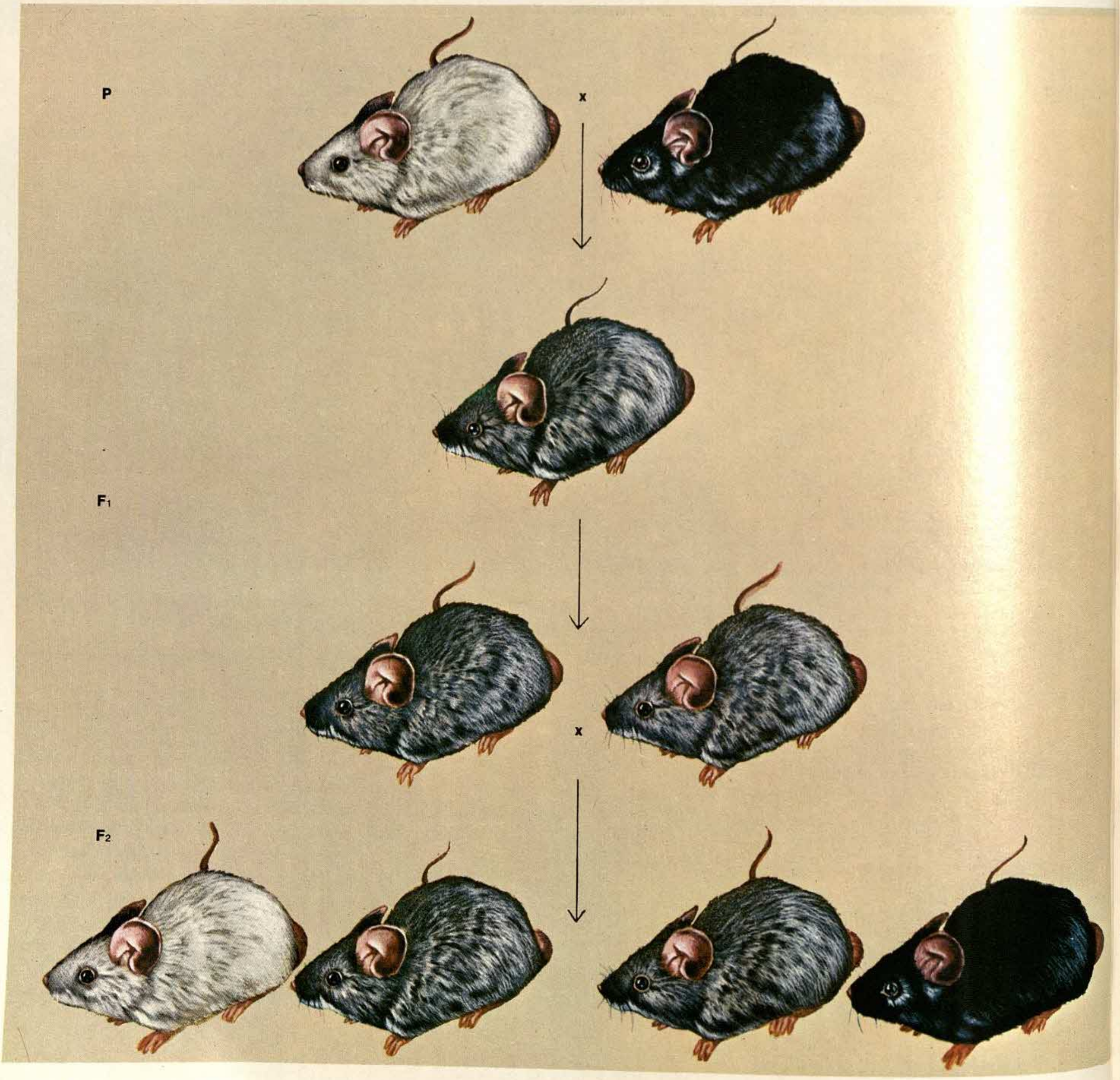


were published in 1865 but did not receive wide recognition until about 1900.

MENDEL'S LAW OF SEGREGATION

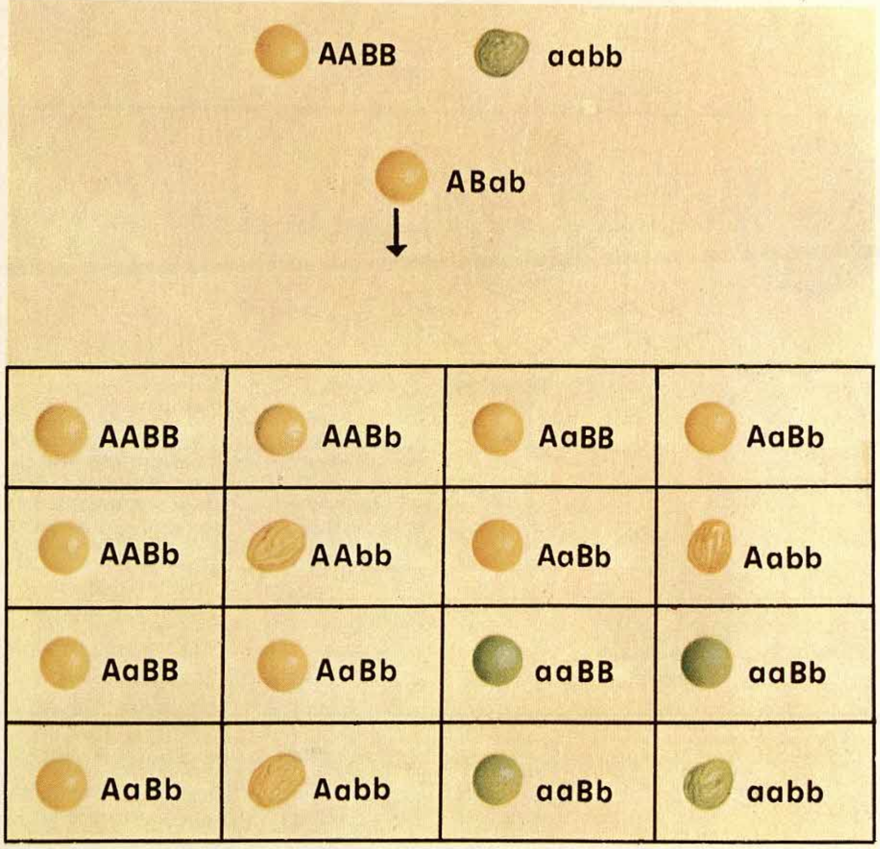
For one of his early experiments Mendel established two pure-breeding lines of peas that produced yellow seeds and green seeds. He crossed these two varieties by transferring pollen from a plant of the yellow variety to one of the green variety, and from the green to the yellow variety. In either case the results were the same—all the seeds produced by these plants were yellow. Mendel described yellow as being dominant to green, and green as being recessive to yellow.

Mendel then collected the yellow seeds produced in this experiment and planted them the next year. When the resulting plants matured, he allowed them to produce seeds by self-pollination. He was surprised to find that the new crop of seeds was not all yellow. The total yield was 8,023 seeds, of which 6,022 were yellow and 2,001 green (a ratio of 3:1).

From these data Mendel reached several conclusions. One conclusion was that hereditary material exists as small particles, which are now known as genes. Another conclusion was that each of the two plants of the original parental generation must have carried two genes for seed color; the yellow-seeded variety carried two genes for yellow, and the green-seeded variety carried two genes for green. Their offspring (known as the first filial generation, or the F_1) must have genes **A** and **a**, one received from each parent. (See illustrations 1, 2, and 3 for graphic examples of Mendel's laws in operation).

A similar experiment is shown in Illustration 4, in which red flowers are dominant to white flowers. The genes are

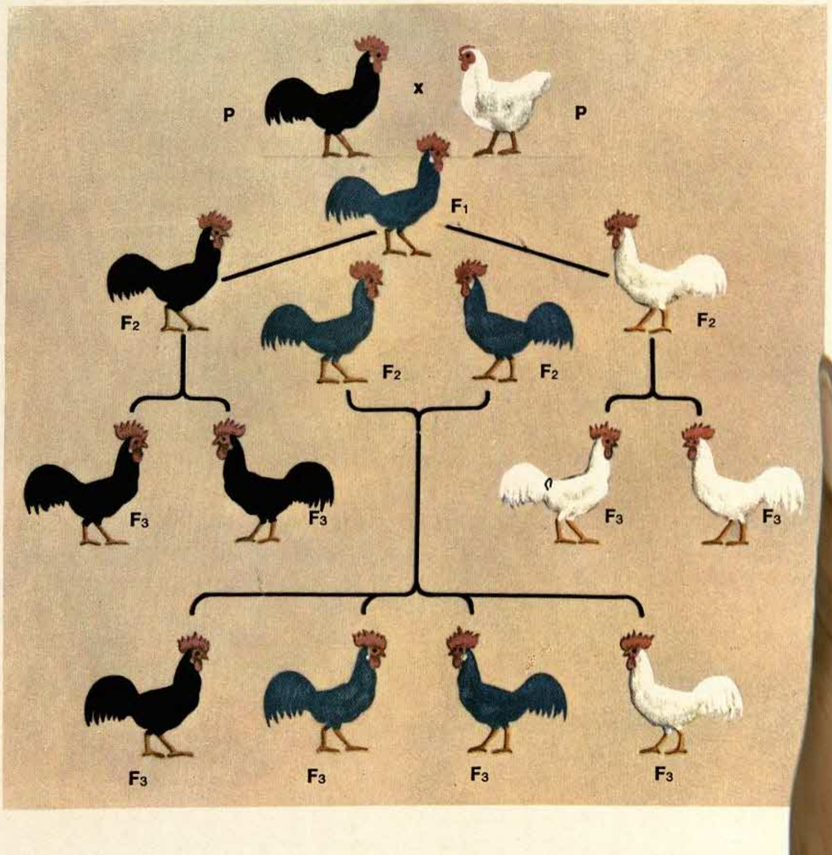
2



AABB	AABb	AaBB	AaBb
AABb	AAbb	AaBb	Aabb
AaBB	AaBb	aaBB	aaBb
AaBb	Aabb	aaBb	aabb

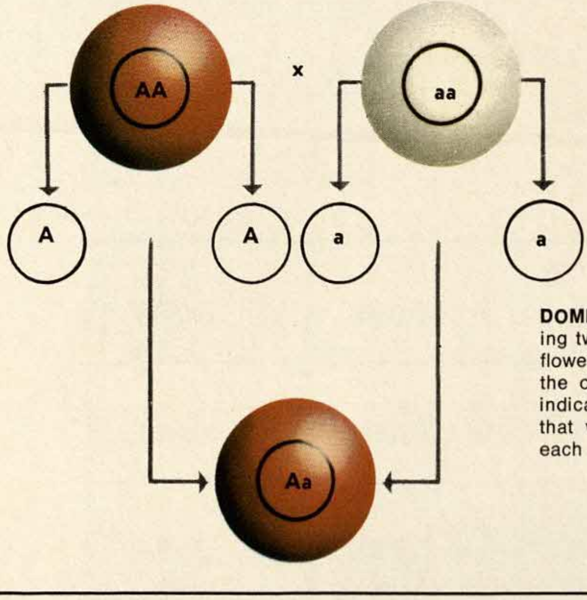
MENDEL'S LAW OF INDEPENDENT ASSORTMENT—This illustration represents the cross between a pea plant grown from a yellow, round seed, and a pea plant grown from a green, wrinkled seed. The cross produces only yellow, round seeds (F_1). When these seeds are sown and the resulting plants are allowed to produce seeds by self-pollination, a ratio of 9:3:3:1 results in the F_2 generation. The dominant characters are indicated by capital letters (**A**, yellow; **B**, round) and the recessive by small letters (**a**, green; **b**, wrinkled). Notice that it is possible for an individual to be homozygous for one pair of genes and heterozygous for another.

3



INCOMPLETE DOMINANCE—In chickens, black and white color are incompletely dominant to each other. The hybrid offspring of a cross between a black chicken and a white chicken is bluish in color and is called an Andalusian chicken. When black chickens are crossed with black chickens, they produce only black chickens. Similarly, when white chickens are crossed with white chickens, they produce only white chickens. But when two Andalusian chickens are crossed with each other, they produce offspring in the ratio of 25 percent black, 50 percent Andalusian, and 25 percent white.

4



DOMINANCE—If a red-flowered plant carrying two genes for red is crossed with a white-flowered plant carrying two genes for white, the offspring may all have red flowers. This indicates that red is dominant to white, and that white is recessive to red. The gametes each carry only one gene.

transmitted from parents to offspring in single cells known as gametes; the gametes of the female parent are eggs, and those of the male parent are sperms. Each offspring originates by the fusion of an egg and a sperm.

Nearly all the cells of an individual contain pairs of genes: **AA, Aa,** or **aa.** But each gamete, or reproductive cell, contains only one gene of a pair; the two members of a pair become segregated when gametes are formed, and the two genes pass to separate gametes. The most clear evidence of this is the result of the self-pollination of the F_1 to produce the F_2.

Each F_1 plant produces equal numbers of sperms bearing genes **A** and **a** and equal numbers of eggs bearing genes **A** and **a.** In each case the dominant gene A and the recessive gene a become segregated. Since sperms bearing **A** and **a** are equally likely to fuse with eggs bearing **A** or **a,** the combinations **AA, Aa,** and **aa** are likely to occur in the F_2 in proportions of 25 percent, 50 percent, and 25 percent respectively.

Mendel knew that his Law of Segregation would prove itself correct, if the F_2 seeds were planted and the resulting plants were allowed to produce more seed by self-pollination, and if the green seeds of the F_2 produced offspring with only green seeds (for they have genes only for green). Mendel reasoned that among the yellow F_2 seeds, only a third of them (those with genes **AA**) should produce plants with only yellow seeds, and two-thirds of them (those with genes **Aa**) should produce plants bearing 75 percent yellow and 25 percent green seeds, for these F_2 yellow seeds are genetically identical with the F_1 seeds and therefore should produce the same kinds of offspring. When Mendel checked this by permitting self-pollination in the F_2 generation, the offspring were produced just as predicted.

INCOMPLETE DOMINANCE

Mendel experimented with pairs of traits other than seed color, and in each case he found that one member of each pair is dominant to the other. For example, round seeds are dominant to wrinkled seeds, and tall stems are dominant to short stems. More recent research has revealed that not all pairs of inherited traits have one member dominant to the other. In mice, for example, neither white nor black fur is dominant to the other, and a mouse possessing one gene for black and one for white has gray fur (Illustration 1). Similarly, in chickens, pairing a gene for white and a gene for black results in bluish-colored feathers (Illustration 3). This relationship is incomplete dominance. Dominance can range from complete, through incomplete, to excessive (a heterozygote more extreme than either homozygote).

HOMOZYGOSITY AND HETEROZYGOSITY

An individual carrying two identical genes (either **AA** or **aa**) is said to be homozygous (from the Greek *homos,* meaning "same"). If the individual carries two different genes affecting the same trait (**Aa**), he is said to be heterozygous (from the Greek *heteros,* meaning "different"). Heterozygotes are hybrids.

INDEPENDENT ASSORTMENT

After performing experiments involving just one trait, Mendel turned to experiments involving two traits. In one of these he crossed two pea plants, one derived from a pure-breeding line with only yellow round seeds, and the other from a pure-breeding line with only green wrinkled seeds. F_1 seeds exhibited both dominant characters and were yellow and round. The F_2 generation contained not only the two parental types, but it also contained two new types, yellow wrinkled and green round. Illustration 2 shows the ratio to be 9 yellow round: 3 yellow wrinkled: 3 green round: 1 green wrinkled: when gametes form, the genes determining color pass to different gametes independently of the genes determining seed shape. Thus the F_1 plants, which are heterozygous for both pairs of genes (**AaBb**, where **B** stands for round, **b** for wrinkled), can produce four kinds of eggs or sperms: **AB, Ab, aB,** and **ab.** These are produced in equal numbers. Since any sperm is equally likely to unite with any egg, the sixteen combinations indicated in Illustration 2 are possible in F_2. The genes for color are thus said to assort independently of those for seed shape.

Independent assortment has been demonstrated in animals as well as in plants. In guinea pigs, black hair is dominant to white hair, and short hair is dominant to long hair. If a purebred black, short-haired guinea pig is crossed with a purebred white, long-haired guinea pig, the F_1 pigs are all black with short hair. If these are crossed with each other, the F_2 members occur in the ratio of 9 black, short-haired: 3 black, long-haired: 3 white, short-haired: 1 white, long-haired. Thus Mendel's laws operate throughout the natural world: timeless and precise.

LINKAGE AND CROSSING OVER

the exchange and association of traits

Although the simple laws of heredity were discovered by the monk Gregor Mendel in 1865, they did not come to the attention of the world's scientific community until 1900, when they were simultaneously confirmed by three geneticists. The immediate acceptance of these laws made them the basis of the modern science of genetics, so named in 1906 by British biologist William Bateson.

INDEPENDENT ASSORTMENT

One of Mendel's laws, however, was soon found to be not universally true. His second law, the Law of Independent Assortment, stated that when an individual forms gametes (eggs or sperms), any two pairs of genes assort independently of each other. If, for example, an individual has two pairs of genes, **Aa** and **Bb**, then when gametes are formed, genes **A** and **a** go into different gametes independently of the movement of genes **B** and **b.** Because of this, four types of gametes can be formed by this individual: **AB,** **Ab**, **aB**, and **ab.** (If only dominant genes were to go into one gamete and only recessive genes into another, then only two types of gamete could be formed: **AB** and **ab**. Mendel did not find any evidence for this type of assortment; nor did he find any evidence that only gametes with genes Ab and **aB** were formed.)

Independent assortment is responsible for the 9:3:3:1 phenotype ratio in the offspring of a cross between two individuals of the genotype **AaBb.** Independent assortment is also responsible for a 1:1:1:1 phenotype ratio when one parent has the genotype **AaBb** and the other has **aabb.** Illustration 1 shows that the **AaBb** parent can produce four types of gametes, but the **aabb** parent produces only one type, **ab.** As a result, four different phenotypes occur among the offspring. Because the four types of gametes of the **AaBb** parent are formed in equal numbers, the four phenotypes of the offspring occur in equal numbers.

LINKAGE

As early as 1906 it was discovered that not all pairs of genes behave in this way, and in 1911 the American biologist T. H. Morgan proposed that pairs of genes located on the same pair of chromosomes are linked physically and thus do not assort independently. Morgan and his associates used the fruit fly *Drosophila melanogaster* for research on this subject. This insect normally has a grayish body color, but some mutant forms have a black color, especially in the posterior of the body. Normal body color **B** is dominant to black body color **b.** Normal wings in *Drosophila* are large and are held over the posterior portion of the body. A mutant form that cannot fly has vestigial wings which are small and wrinkled and are held outward from the body. Normal wings **V** are dominant to vestigial wings **v.**

A portion of one of Morgan's experiments is outlined in Illustration 3. A female fly heterozygous for both body color and wing type (**BbVv**) was mated with a male fly homozygous for black body color and vestigial wing (**bbvv**). If the pair of genes **B** and **b** segregated independently of genes **V** and **v**, then the offspring would be of four different phenotypes (¼ normal body color, normal wing; ¼ normal body color, vestigial wing; ¼ black body color, normal wing; and ¼ black body color, vestigial wing) occurring in equal numbers. Instead, more than 80 percent of the offspring fell into two classes: normal body color with vestigial wings and black body color with normal wings. From this, Morgan concluded that the genes for body color and wing shape must be linked and that they were on the same pair of chromosomes. In this particular female the genes **B** and **v** were on the same chromosome, and the genes **b** and **V** were on the homologous chromosomes.

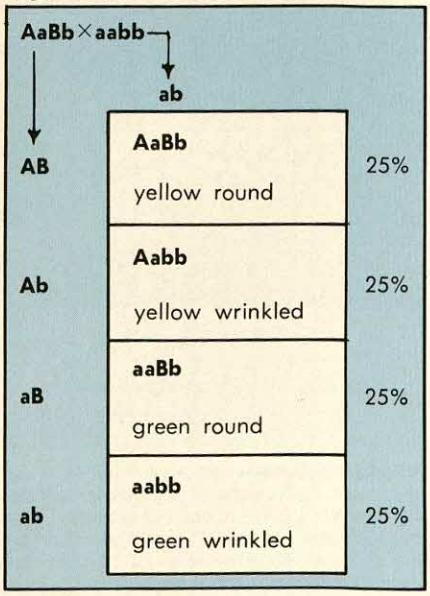
The eggs of this female, like the gametes of any animal, were formed by a special type of cell division called meiosis. In this division, the chromosomes and all the genes they bear are duplicated, and the cell divides twice, forming four cells each with half of the chromosomes of the original cell. If the two pairs of genes of this female fly were linked, then one would expect half of her eggs to have the genes **B** and **v**, and half to have **b** and **V.** As a result, when she is mated with a **bbvv** male, half of the offspring would be expected to have normal body color and vestigial wings, and half would be expected to have black body color and normal wings. The results of Morgan's experiment were close to this, but a few offspring were of types that could not be explained by linkage alone.

CROSSING OVER

In the cross described above, an offspring that had normal body color and normal

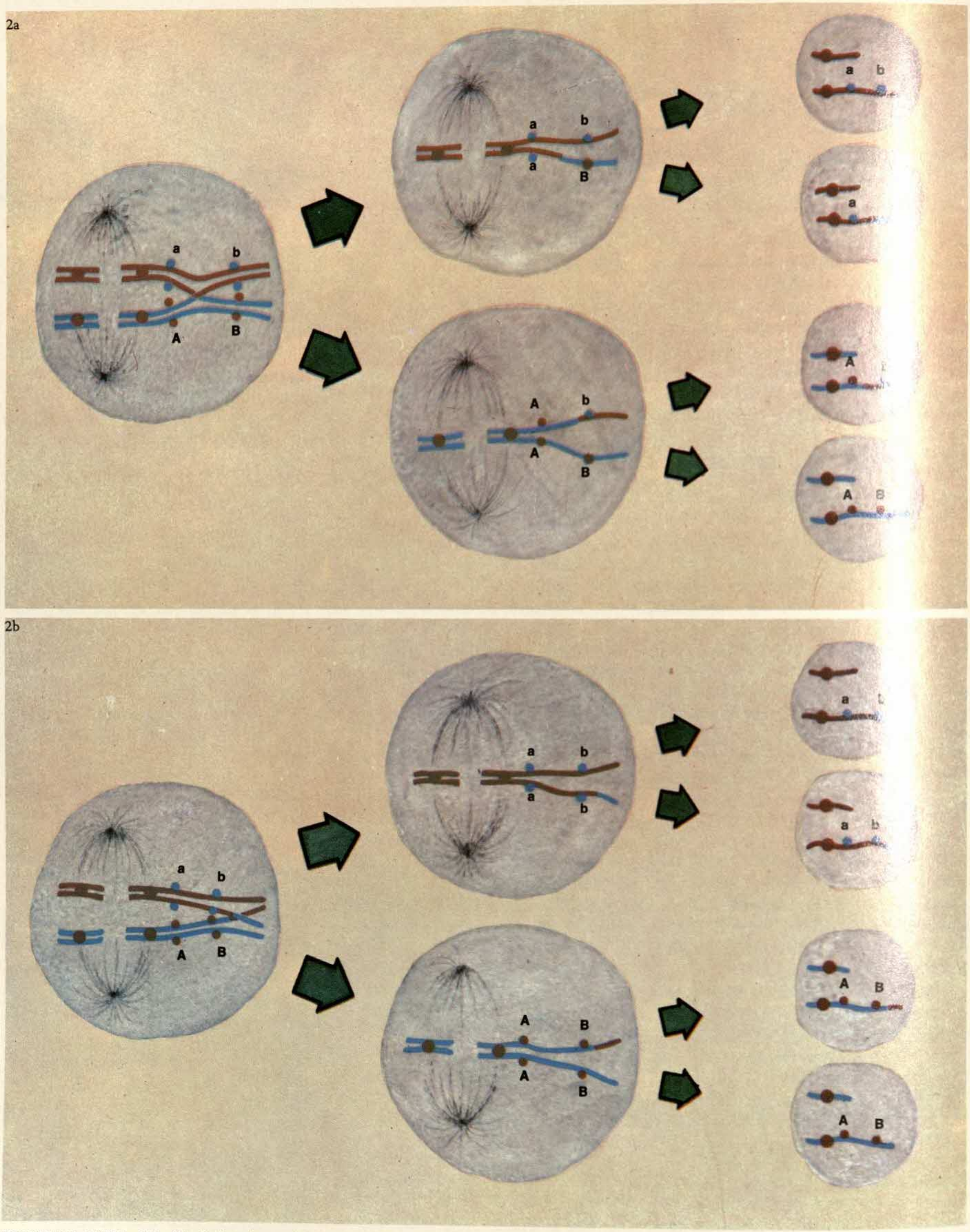
1

A RATIO OF 1:1:1:1—A cross between an individual heterozygous for two pairs of genes and an individual homozygous for the corresponding recessive genes gives a phenotype ratio of 1:1:1:1 if the two pairs of genes are on different pairs of chromosomes. **A**, yellow; **a**, green; **B**, round; **b**, wrinkled.



AaBb × **aabb**

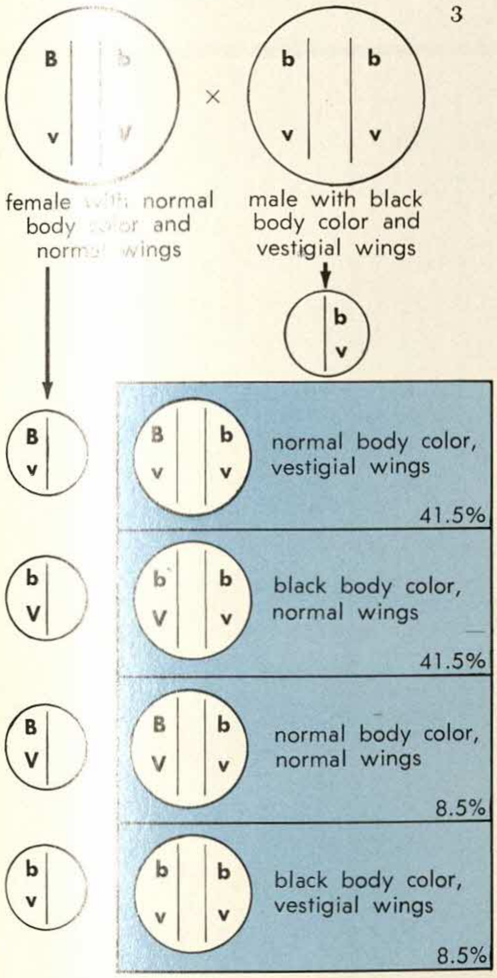
	ab	
AB	**AaBb** yellow round	25%
Ab	**Aabb** yellow wrinkled	25%
aB	**aaBb** green round	25%
ab	**aabb** green wrinkled	25%



CROSSING OVER—This illustration is a diagrammatic representation of crossing over during meiosis; spindle fibers and aster rays have been deleted to avoid confusion. The two homologous chromosomes of a pair are colored differently for ease in distinguishing them; in living cells the chromosomes are colorless. If crossing over occurs between two pairs of genes, four different gametes are produced. If no crossing over occurs, or if it occurs elsewhere than between the two pairs of genes, then only two types of gametes are produced (see text for details).

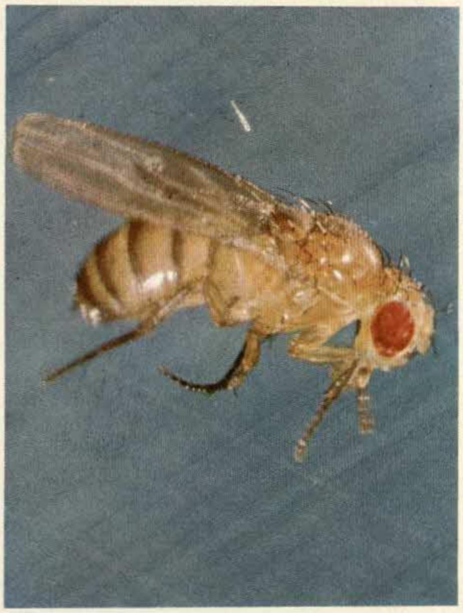
Crossing over does not occur in male fruit flies. In female fruit flies only one of the four cells matures into an egg, but because many cells undergo meiosis simultaneously, a large number of eggs are formed by any female.

3

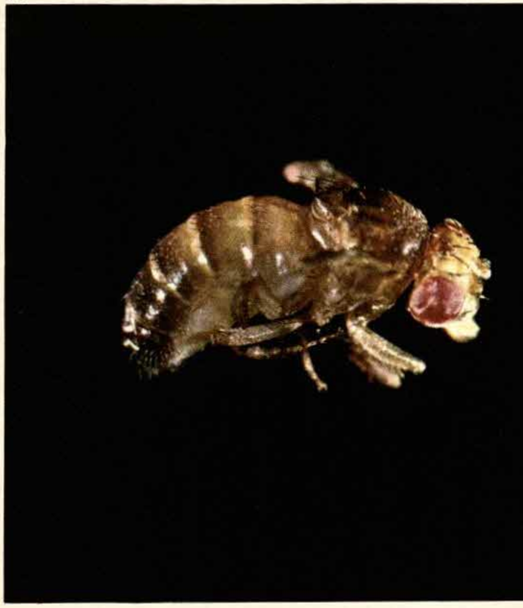

B
b
v
V
×
b
b
v
v
female with normal body color and normal wings
male with black body color and vestigial wings
b
v
B
v
B
b
v
v
normal body color, vestigial wings
41.5%
b
V
b
b
V
v
black body color, normal wings
41.5%
B
V
B
b
V
v
normal body color, normal wings
8.5%
b
v
b
b
v
v
black body color, vestigial wings
8.5%

LINKAGE AND CROSSING OVER—On the basis of linkage alone, gametes **Bv** and **bV** are the only gametes that would be expected from the female parent indicated here. Gametes **BV** and **bv** result from crossing over. Because 17 percent of the gametes have crossover chromosomes, the phenotype ratio among the offspring is 41.5:41.5:8.5:8.5. **B,** normal body color; **b,** black body color; **V,** normal wing, **v,** vestigial wing.

4a



4b

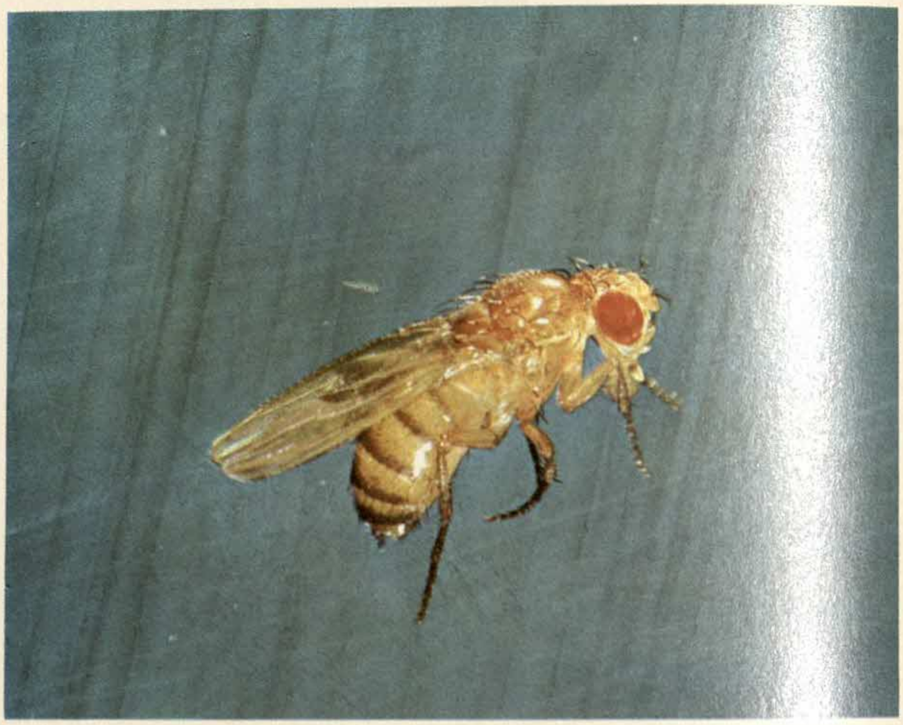


4c

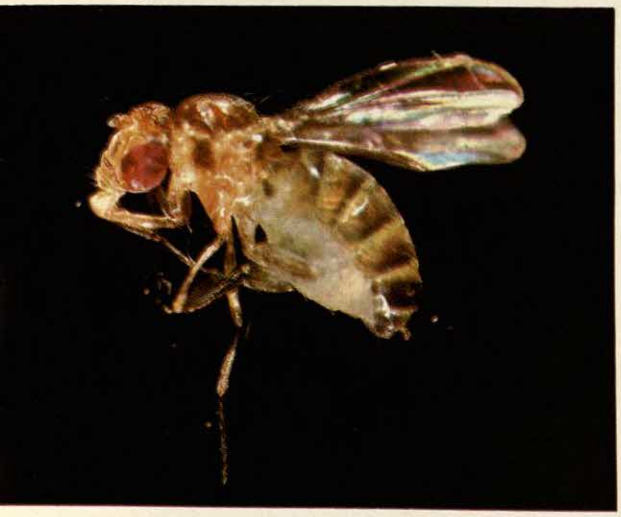
SOME PHENOTYPES IN *DROSOPHILA*—A female fly with normal body color and normal wings and genotype **BBVV** is shown in Illustration 4a. The male fly in Illustration 4b has black body color and vestigial wings; his genotype is **bbvv.** If these two flies are mated, their offspring will all have normal body color and normal wings (Illustration 4c), and their genotypes will be **BbVv.**

SECOND GENERATION—When a normal grayish heterozygote female *Drosophila* with normal wings characteristic of the first generation (5a) is crossed with a black homozygote male with vestigial wings (5b), the second generation includes four distinct types: one grayish with normal wings (5c); one black with vestigial wings (5d); one grayish with vestigial wings (5e); and one black with normal wings (5f). In the first two instances, the characteristics that are manifested are the same that were dominant before the crossing over. In the other two, there are unexpected results:

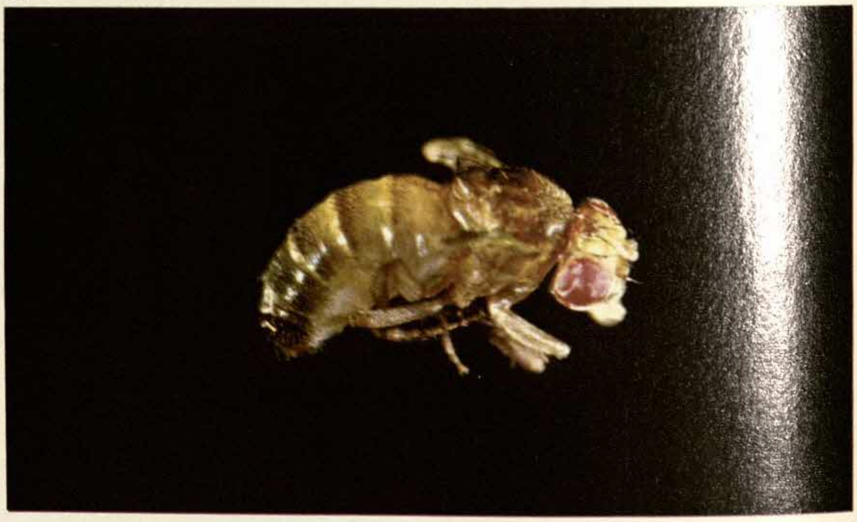
5a



5c



5d



wings could have come only from an egg that had genes **B** and **V.** Similarly, an offspring with black body color and vestigial wings could have come only from eggs that had genes **b** and **v.** Because these two pairs of genes are linked, eggs with **BV** or **bv** could not have been produced by independent assortment. They could have arisen, however, by the exchange of materials between the two chromosomes when the eggs were formed. This exchange of materials is called crossing over; if a crossover occurred between the loci of genes **B** and **b** and the loci of genes **V** and **v** in the female fly, then she could indeed produce gametes **BV** and **bv.**

Illustration 2 shows some of the phases of meiosis. Illustration 2a shows one pair of homologous chromosomes with the loci of two pairs of genes indicated. Each chromosome and its genes have already been duplicated; each duplicate of a chromosome is called a chromatid. This cell is in early prophase of the first division. In Illustration 2b, two chromatids of two homologous chromosomes lie across each other; if they break and exchange fragments (containing genes **V** and **v**) at this point, a crossover occurs. This cell is in a later stage of prophase of the first division. The chromosomes shown in Illustration 2c are the result of a crossover; this cell is in anaphase of the first division. The same chromosomes are seen in Illustration 2d where they have gone into separate daughter cells. Meiosis is completed when these two cells divide and form four cells (Illustration

5b

the types seem to behave according to a law of independent origin. It is precisely their behavior that enabled Morgan to discover the phenomenon of crossing-over.

Drosophila melanogaster is the subject most commonly used for research and experimentation on heredity and evolution. In the laboratory, the fruit flies are bred in a simple thick glass bottle and fed a nourishing paste of cornmeal and water and a small amount of glucose. The bottles are sealed with cotton and maintained at a constant temperature of from 20° to 25° C (68° to 77° F).

5e

5f

2e). Of the four cells, two have chromosomes like those of the parent cell (**Bv** and **bV**), and two have new combinations (**BV** and **bv**) resulting from the crossover.

Crossovers between any pair of genes do not occur every time a cell undergoes meiosis; only a certain percentage of dividing cells have crossovers between any pair of genes—and, moreover, the crossover percentage varies with different pairs. In crossovers the genes are arranged linearly along the chromosomes.

CHROMOSOME MAPS

The discoveries of linkage and crossing over have been invaluable in the preparation of chromosome maps on which the loci of genes are indicated. From the results of many matings, it is possible to determine which genes are linked to each other and which assort independently of each other. All those genes that are linked with each other are located on the same chromosome.

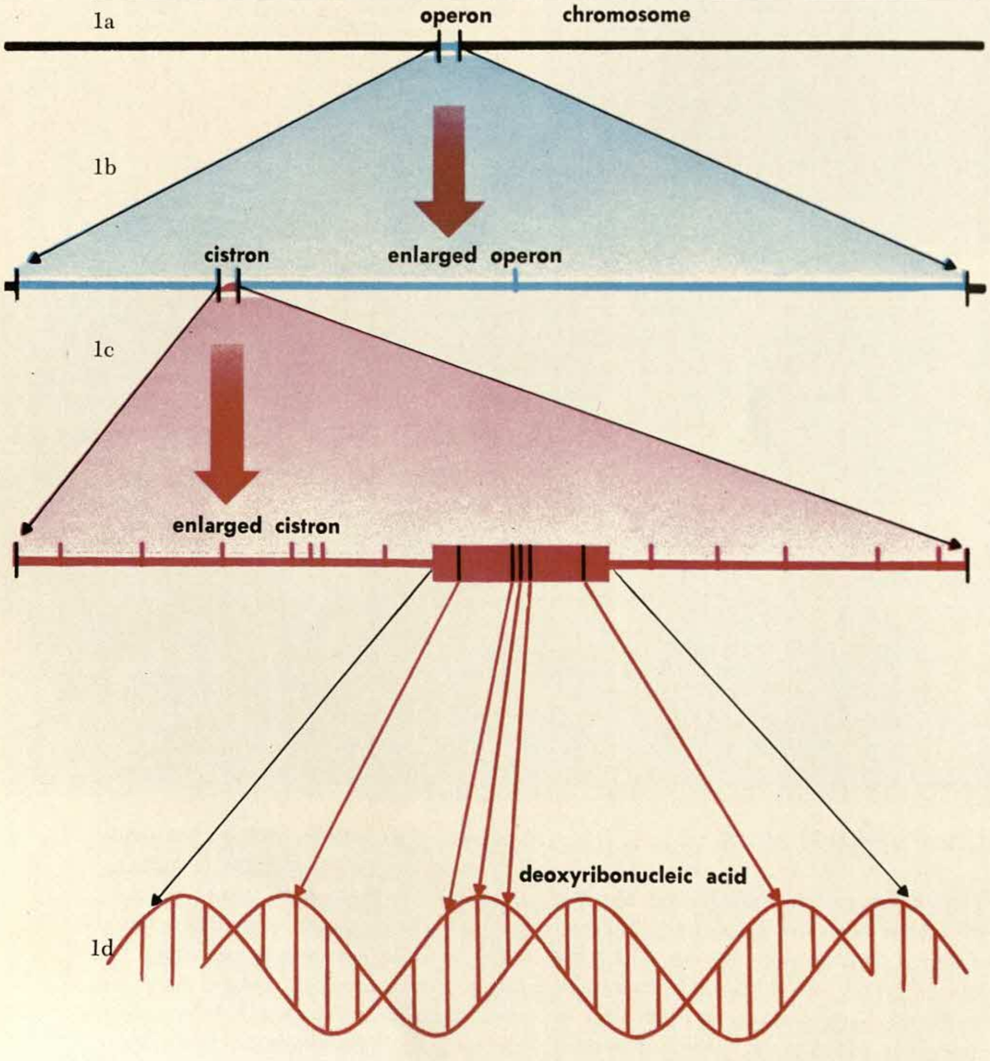
After a linkage group has been discovered, then further matings are made to determine the percentages of crossing over. The farther apart genes are on a pair of chromosomes, the more likely there is to be a crossover occurring between them; accordingly, if the genes are close together, crossovers between them are rare. By determining the percentage value of crossovers for all possible pairs of genes on any pair of homologous chromosomes, it is possible to calculate the approximate distances between the genes and thus to construct a chromosome map.

THE BIOCHEMISTRY OF GENETIC MATERIAL

genetics on the molecular level

What is a gene? The classic concept developed by the early geneticists portrayed it as a well-defined, indivisible unit situated at its own particular locus on a chromosome. The gene is still thought to occupy a definite locus, but it is now envisioned as a more complicated structure than it once was.

The function of genetic material is the control of the many chemical reactions that determine an individual's phenotype (his actual characteristics). Each biochemical pathway consists of a series of reactions, with the product of each reaction in the series being the raw material of the next reaction. Each reaction in the pathway is catalyzed by its own particular enzyme.



THE SUBMICROSCOPIC STRUCTURE OF THE CHROMOSOME—The chromosome represented in black (Illustration 1a) is composed of a great number of units, the operons. One of these, shown as a blue line, is enlarged in Illustration 1b and the small red portion, representing a cistron, is enlarged in Illustration 1c. This portion is composed of about 1,500 nucleotides. Illustration 1d shows a small portion of a cistron, that is, a bit of DNA. The variations in the chemical composition of the DNA are responsible for mutations.

An enzyme is a protein that consists of one or two polypeptide molecules, and the catalytic properties of the enzyme depend to a large extent on its amino acid content and the precise arrangement of the amino acids in the polypeptides. Genetic material exerts its effect on biochemical reactions by controlling the numbers, kinds, and arrangements of amino acids within the enzyme molecules.

The genetic material on a chromosome is divided into units called operons, each operon usually controlling one biochemical pathway. Operons themselves are subdivided into several units called cistrons, each of which controls the synthesis of one polypeptide. A gene is commonly equated with a cistron.

Cistrons themselves are not indivisible. Mutations (changes in genes) can occur at more than one locus in a cistron, and crossovers can occur between the loci of a cistron. Illustration 2a shows the cistrons of a pair of homologous chromosomes of an individual heterozygous for two mutations. Each cistron has one of the mutations, **e** or **e′**, at a different locus. The normal, unmutated (wild type) loci are indicated by +. Each mutant locus prevents its cistron from producing the normal polypeptide; thus an individual with these two cistrons lacks that enzyme.

If crossing-over occurs between **e** and **e′**, it is possible for individuals with the cistrons shown in Illustration 2b to occur. The mutations still prevent the one cistron from controlling the production of its polypeptide; but the other cistron, being free of mutations, does produce the polypeptide, and the individual possesses the enzyme. Both individuals have the same genetic material, but their phenotypes are different because the material is distributed differently between the two homologous cistrons.

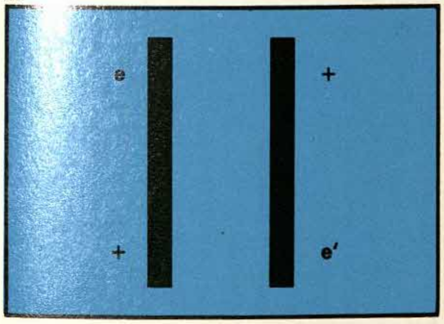
THE CHEMICAL STRUCTURE OF THE GENETIC MATERIAL

The genetic material of all cells is deoxyribonucleic acid (DNA). The quantity of DNA is the same in all cells of an individual except in the eggs and sperms, which contain only half the amount.

DNA consists of two long, helical strands wound around each other. Each strand is a chain of smaller units called nucleotides. Each nucleotide consists of a nitrogen base, a phosphate group, and the sugar deoxyribose. The nucleotides in each strand of DNA are joined to each other through their deoxyribose and phosphate groups. The two strands of the DNA molecule are bonded to each other through their nitrogen bases. The nitrogen bases are of two types: pyrimidines (cytosine and thymine) and purines (guanine and adenine). The cytosine of one strand is always bonded to the guanine of the other strand, and the thymine of one strand is always bonded to the adenine of the other strand. The two strands, then, are not identical but complementary.

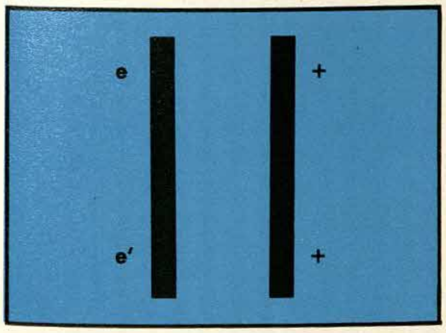
CROSSING-OVER WITHIN A CISTRON—Illustration 2a shows two cistrons, each bearing one mutation. No enzyme can be produced by either cistron. If crossovers occur (Illustration 2b), a cistron without mutations results, and the enzyme can be produced.

2a



mutant phenotype

2b



wild type

The bonds between the nitrogen bases are called hydrogen bonds. Although they are individually weak, the many hydrogen bonds along the length of the molecule collectively are strong.

REPLICATION OF DNA

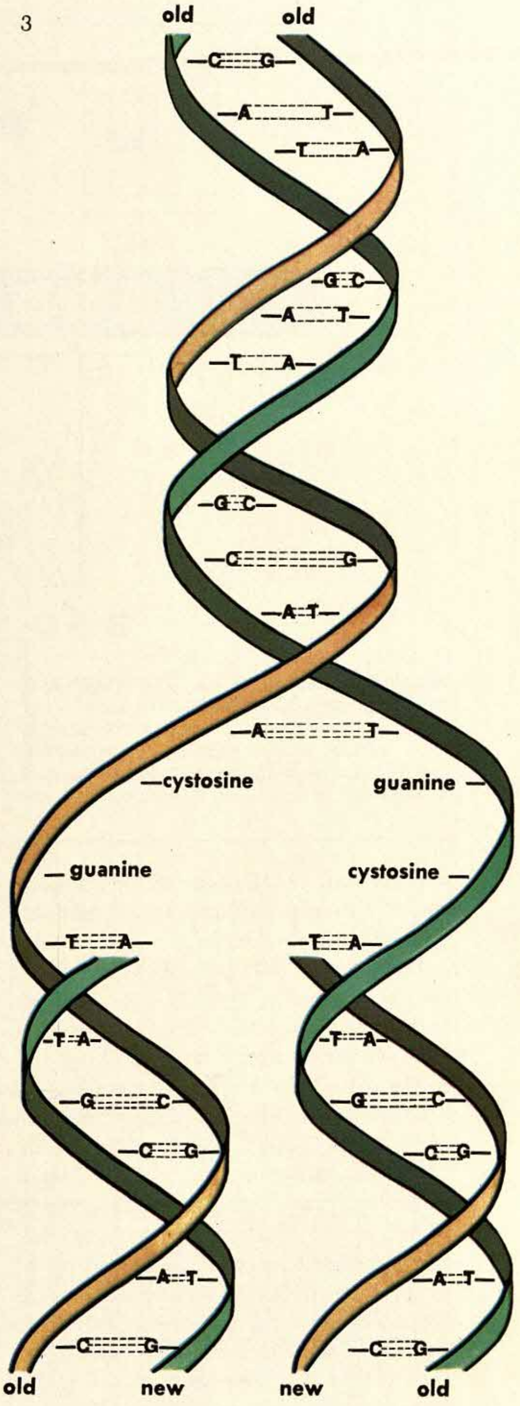
When cell division occurs, the DNA replicates itself, producing two identical DNA molecules that are transmitted from the parent cell to the daughter cells. The first step in replication is the separation of the two complementary strands as the hydrogen bonds break (Illustration 3). The separation begins at one end of the molecule and proceeds toward the other end. As each nucleotide is exposed, it attracts a complementary nucleotide to it. When the new nucleotides are arranged in place, they react chemically with each other, forming new strands complementary to the old ones. Each new strand is bonded by hydrogen bonds to one of the old strands. In this way, two identical, double-stranded DNA molecules are produced.

THE GENETIC CODE

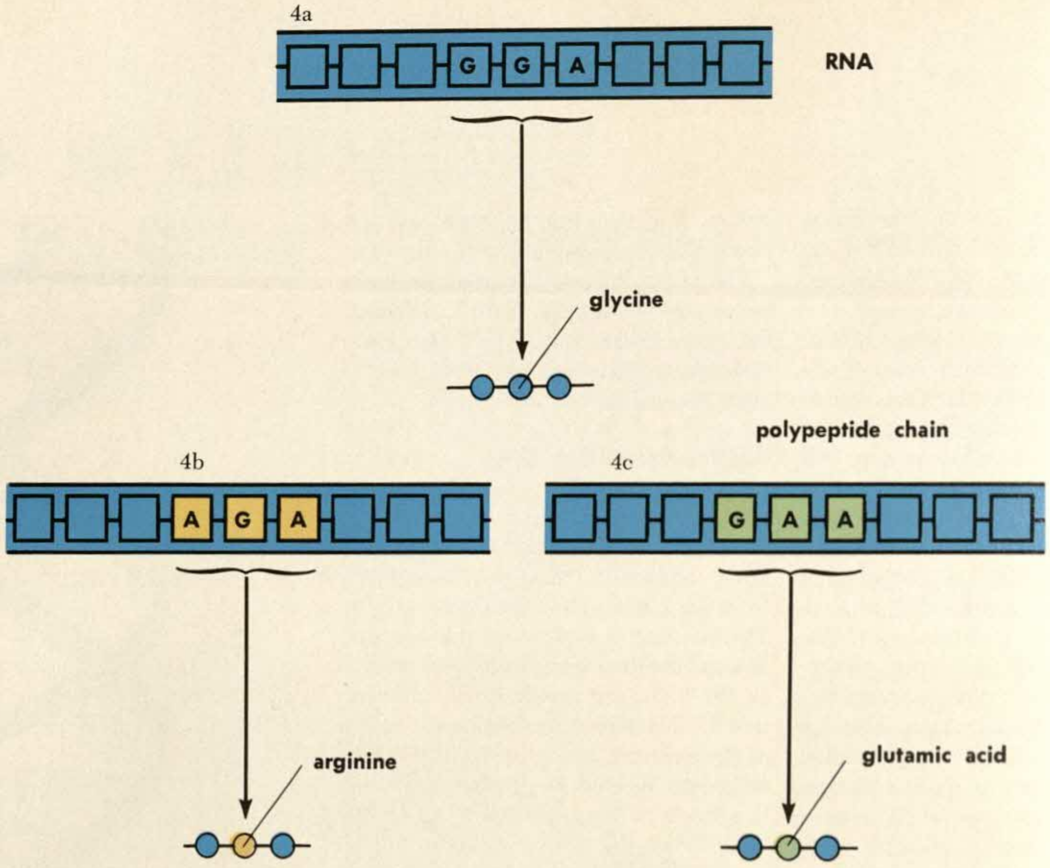
The genetic code, which controls the synthesis of polypeptides, resides in the DNA molecule. The code has been compared with a vocabulary of three-letter words made from an alphabet of four letters. The letters here are the nitrogen bases: adenine (A), cytosine (C), guanine (G), and thymine (T). The words are sets of three nucleotides called triplets or codons. The triplet ACG, for example, indicates that one molecule of the amino acid threonine is to be used in the synthesis of a polypeptide. If the next triplet is CAC, then the amino acid histidine follows the threonine. An entire cistron is "read" in this way, always in triplets, each triplet coding for one amino acid. Because there are 64 possible triplets and only about 20 amino acids used by cells, two or more triplets may code for the same amino acid.

Many polypeptides are composed of about 500 amino acids, although there is

3



DUPLICATION OF DNA—This illustration shows not only the double helix of the DNA molecule but also its duplication. The two helices first separate from each other as shown at the bottom. Then each nucleotide in an old helix attracts nucleotides with complementary bases, and two new helices are formed.



RELATION BETWEEN A CISTRON AND POLYPEPTIDE SYNTHESIS—Because each triplet of nucleotides determines the position of a certain amino acid in a polypeptide chain, changes in the nucleotides cause corresponding variations in the amino acid sequence of the polypeptide. These changes can be so radical as to destroy the enzymatic properties of the protein. In Illustration 4a, the triplet GGA positions the amino acid glycine in a polypeptide. If one nucleotide substitution changes the triplet GGA to AGA, arginine is placed in the polypeptide in the place of glycine (Illustration 4b); this may render the enzyme inactive. In Illustration 4c, a different mutation, GAA, places glutamic acid in the enzyme. Many polypeptides are composed of about 500 amino acids.

a great deal of variation of this. Therefore, a cistron must be about 500 triplets, or 1,500 nucleotides, long.

DNA does not control polypeptide synthesis directly, for DNA is confined to the nucleus of the cell, and polypeptide synthesis occurs on the ribosomes in the cytoplasm. DNA acts through another molecule, the "messenger" ribonucleic acid (RNA). RNA differs from DNA in consisting of a single strand rather than two, and in having the sugar ribose in the place of deoxyribose and the pyrimidine uracil (U) in the place of thymine. RNA is synthesized much like a DNA strand, one of the old DNA strands acting like a template. The RNA thus carries the same code as the DNA except that it has uracil where DNA has thymine. The messenger RNA moves out of the nucleus and into the cytoplasm. When it reaches a ribosome (a tiny, dense granule in the cytoplasm), amino acids are attracted to it in the order dictated by the genetic message it carries. The amino acids are bonded together, forming a polypeptide with enzymatic properties.

MUTATIONS

A change in the arrangement of nucleotides in DNA can cause a change in the order of amino acids in a protein. Such a change in DNA is known as a mutation. It may be caused by the substitution of one nitrogen base for another as is shown in Illustration 4. Such a mutation may or may not be serious. If the substitution of one amino acid for another in a protein molecule destroys its enzymatic character, the individual possessing this mutation may die or be ill because a biochemical pathway has been blocked. If the protein is altered only slightly, no phenotypic effect may be observed.

The deletion or addition of a nucleotide often causes very serious effects. Because the code is "read" from one end of the molecule to another, then all triplets beyond the point of a deletion or addition are misread. For example, if the second nucleotide is lost from CACTGGTAC——, it is no longer read as CAC TGG TAC——, but as CCT GGT AC——. With so many triplets changed, the resulting protein rarely is the correct enzyme.

Mutations are passed from cell to cell and from generation to generation (unless they are lethal), for the altered DNA replicates itself as faithfully as the original DNA.

MUTONS AND RECONS

A muton is the smallest amount of DNA that can mutate. A muton, therefore, is one nucleotide.

A recon is the smallest amount of DNA that can be involved in recombination. Because crossing-over can occur between any two nucleotides, a recon is one nucleotide.

PATTERNS OF INHERITANCE | variations on a genetic theme

When Gregor Mendel, the father of modern genetics, published the results of his research in 1865, he reported traits that are inherited by the typical patterns of simple dominance and recessiveness. Geneticists later discovered the existence of other, more complicated, patterns of inheritance. Among them are sex-linked traits, sex-influenced traits, sex-limited traits, multiple gene inheritance, and epistasis.

SEX-LINKED TRAITS

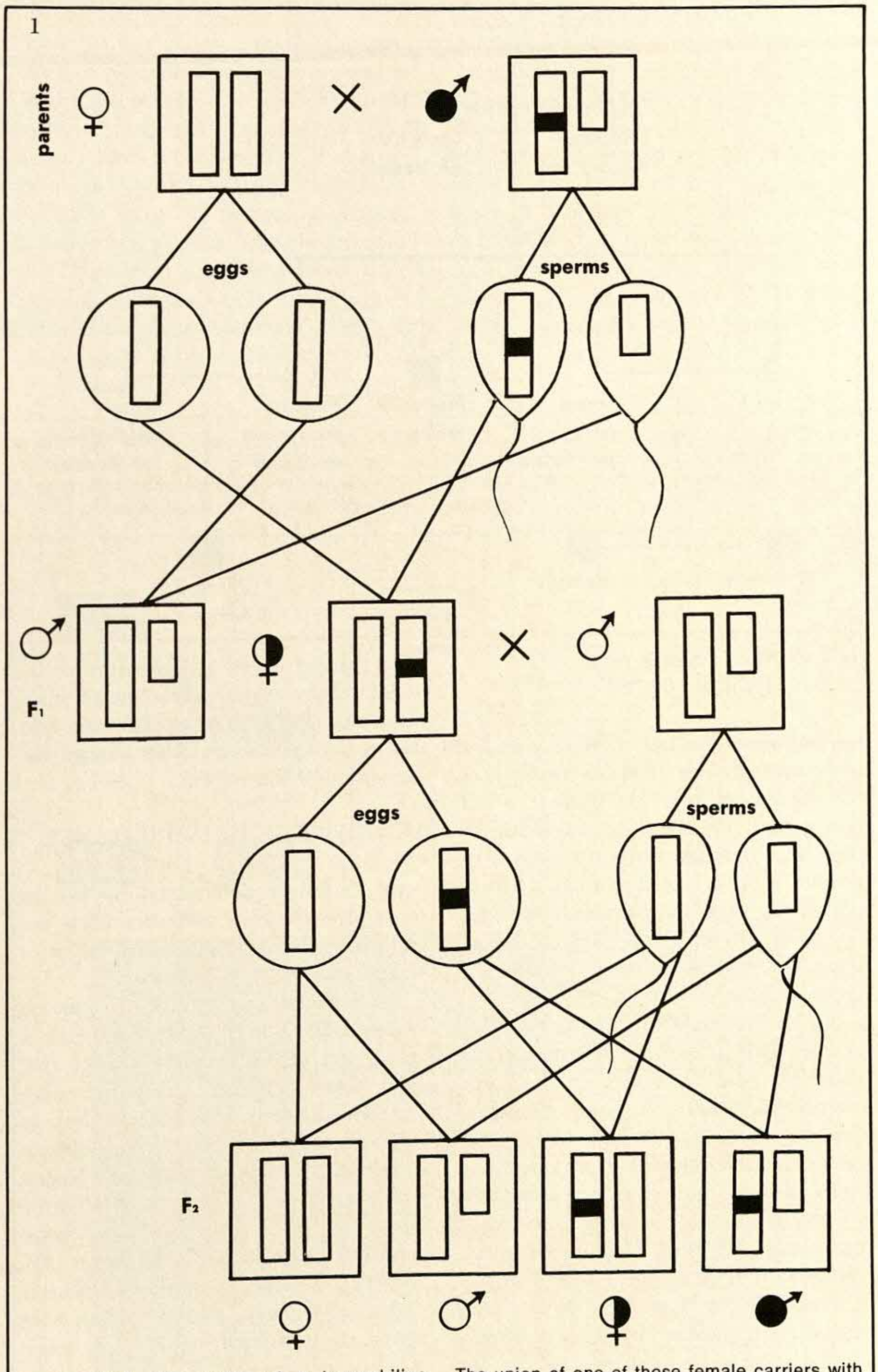
The genes of sex-linked recessive traits are located on the X chromosomes. Consequently, females may be either homozygous or heterozygous for these traits; but males, who have only one X chromosome, are hemizygous with respect to sex-linked traits. Therefore, if a male has a recessive gene on his X chromosome, that gene finds expression because there is no allele on the Y chromosome that might be dominant to it.

Hemophilia, or bleeder's disease, is a sex-linked recessive trait. Because the blood of hemophiliacs does not clot readily, they are unusually subject to hemorrhages and may bleed to death from relatively small cuts. A male hemophiliac passes his recessive gene to all his daughters but to none of his sons; these heterozygous daughters are called carriers. Even if they marry normal men, they can have hemophiliac sons.

Some of the most famous cases of hemophilia were those among the descendants of Queen Victoria of England. Although Victoria was normal in this respect, she carried a mutant gene for the disease. One of her sons was a hemophiliac, and two of her daughters were carriers; several of her grandsons and great grandsons also had hemophilia. Among them were two heirs to royal thrones: Alexis, Czarevitch of Russia, and Alfonso, Crown Prince of Spain.

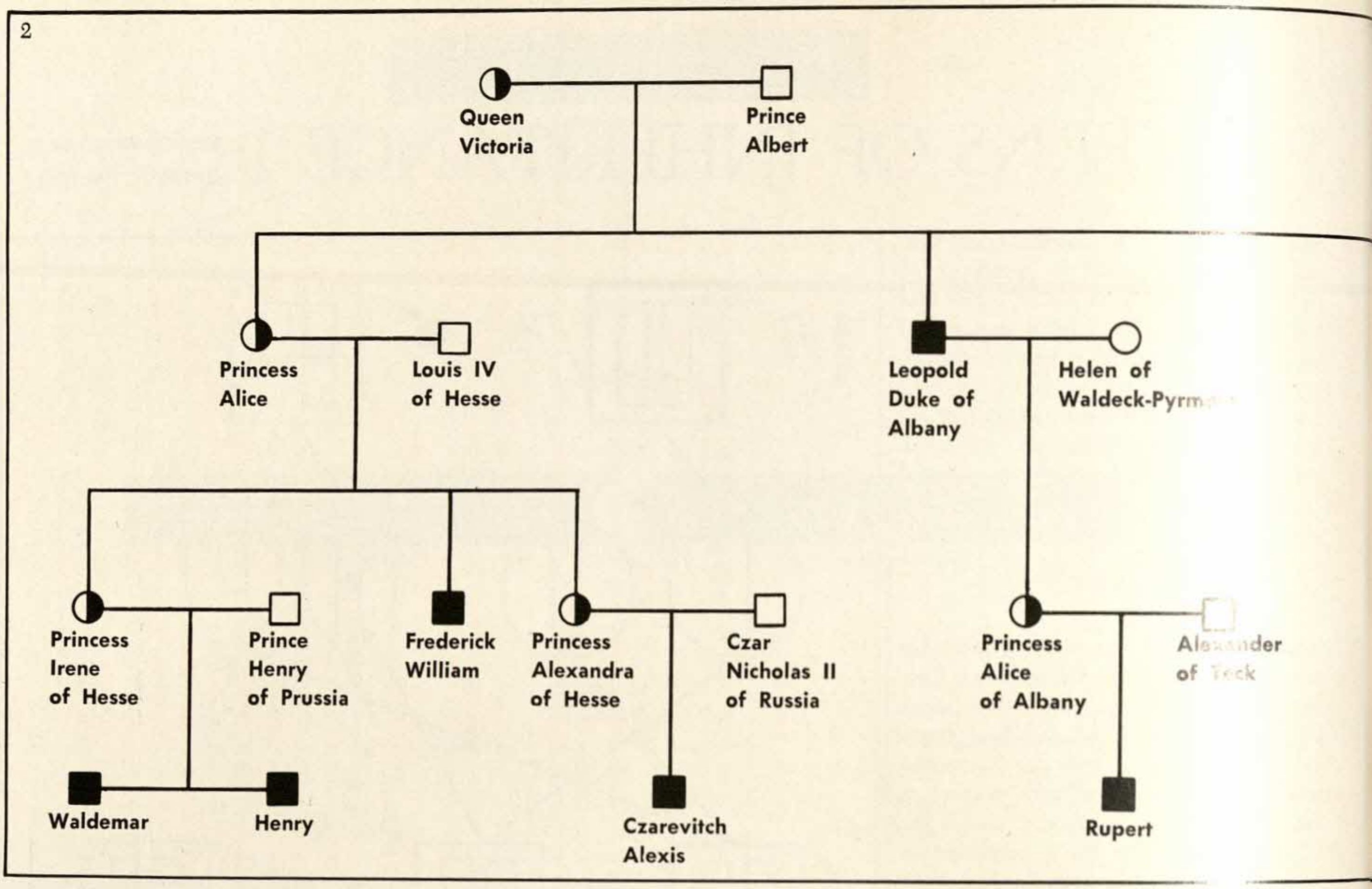
All sex-linked recessive traits are rarer among women than among men, but hemophilia is extremely rare among women. A female hemophiliac must have a hemophiliac father, and few hemophiliacs live long enough to have children.

1



HEMOPHILIA—The union of a hemophiliac man with a normal, homozygous woman produces healthy male and female offspring (F_1). The females, however, will be carriers of the gene (represented in the diagram by a black band) on the X chromosome from the father. The union of one of these female carriers with a normal man can produce normal males; normal, homozygous females; hemophiliac males (indicated by the black symbol); and normal, heterozygous females (indicated by the half-black symbol), who are carriers (F_2).

2



SEX INFLUENCED AND SEX-LIMITED TRAITS

Several genes located on autosomes find different expression in males and females. Sex-influenced traits are those in which one gene is dominant in males and recessive in females, while its allele is recessive in males and dominant in females. One such trait, Heberden's nodes, is a disease in which the finger joints are enlarged; it is dominant in women and recessive in men.

Sex-limited traits are those that find expression in only one sex. Examples include the beard of males and milk production in females. In some species of animals, males and females have fur or feathers of different colors or patterns; in some animals, the males have horns and the females do not. Genes for sex-limited traits may be located on sex chromosomes as well as on autosomes.

The different expression of sex-influenced and sex-limited traits is due largely to the modifying influences of the sex hormones. The presence of male hormones causes the genes to express themselves in the manner characteristic of males, and the presence of the female sex hormones causes the same genes to produce the expression characteristic of females. Experimental injections of male hormones into females or of female hormones into males can often change the expression of these traits.

MULTIPLE GENE INHERITANCE

Some traits are determined by two or more pairs of genes and often these are on different chromosomes. The color of human skin is one such trait.

For purposes of illustration, it may be assumed that two pairs of genes—pair **A** and **a** and pair **B** and **b**—influence skin color. Genes **A** and **B** contribute to dark skin, and the genes **a** and **b** contribute to white skin. Thus a person with the genotype **AABB** has the black skin of a Negro, and a person with genotype **aabb** has the white skin of a Caucasian. The Negro produces gametes with the genes **AB**, and the Caucasian produces gametes with the genes **ab**. If two such persons marry, their children will be of an intermediate mulatto color and will have the genotype **AaBb.**

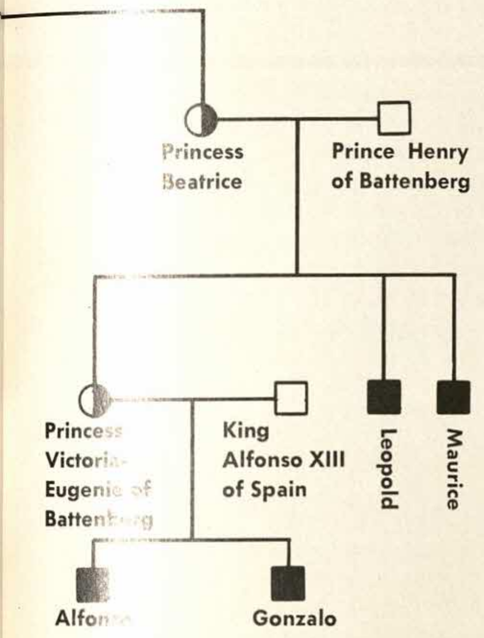
If two persons of the genotype **AaBb** marry, they may have children of several different shades of color. Each parent can produce four different types of gamete: **AB, Ab, aB,** and **ab.** Because any egg can be fertilized by any sperm, nine different genotypes are possible among the offspring. Genotype **AABB** produces black skin. **AABb** and **AaBB** produce a rather dark mulatto shade a little lighter than black. **AAbb, aaBB,** and **AaBb** result in the intermediate mulatto color. **Aabb** and **aaBb** produce light mulatto skin. The genotype **aabb** results in white skin.

The actual number of genes that determine the different shades of skin color is not known with certainty, but it is believed to be at least three and probably more. This alters the above scheme only slightly, by making possible more intermediate shades.

Other traits influenced by multiple gene inheritance are height, weight, and intelligence. In some cases so many pairs of genes are involved that it is impossible to divide a population into distinct classes. Rather, there seems to be a continuum of variations from short to tall, light to heavy, or stupid to intelligent.

Many multiple gene traits are susceptible to modification by the environment. The state of nutrition, for example, may influence height, weight, or intelligence; exposure to sunlight may darken skin

PARTIAL PEDIGREE OF THE FAMILY OF QUEEN VICTORIA—Only those individuals that had hemophilia or were carriers and their spouses are indicated. Many members of this large family did not have the gene. Carriers are indicated by the half-black symbols.


Princess Beatrice
Prince Henry of Battenberg
Princess Victoria-Eugenie of Battenberg
King Alfonso XIII of Spain
Leopold
Maurice
Alfonso
Gonzalo

color. This tends to blur the distinctions between any classes.

EPISTASIS

Some traits are influenced by two pairs of genes, one of the alleles of one or both pairs inhibiting the expression of the other. Several types of this phenomenon, which is called epistasis, are known.

Deaf-mutism in humans is due to duplicate recessive epistasis. This genetic disease is affected by two pairs of genes: **D** and **d**, and **E** and **e**. The genes **D** and **E** produce normal hearing and are dominant to **d** and **e**, respectively. The genes **d** and **e** cause deafness if either one or both of them are present in the homozygous condition. Thus the presence of **dd** causes deafness even if the dominant gene **E** is present, and **ee** also causes deafness even if **D** is present. The following tables shows the genotypes that produce normal hearing and those that cause deaf-mutism:

Normal	Deaf-mutism
DDEE	**DDee**
DDEe	**Ddee**
DdEE	**ddEE**
DdEe	**ddEe**
	ddee

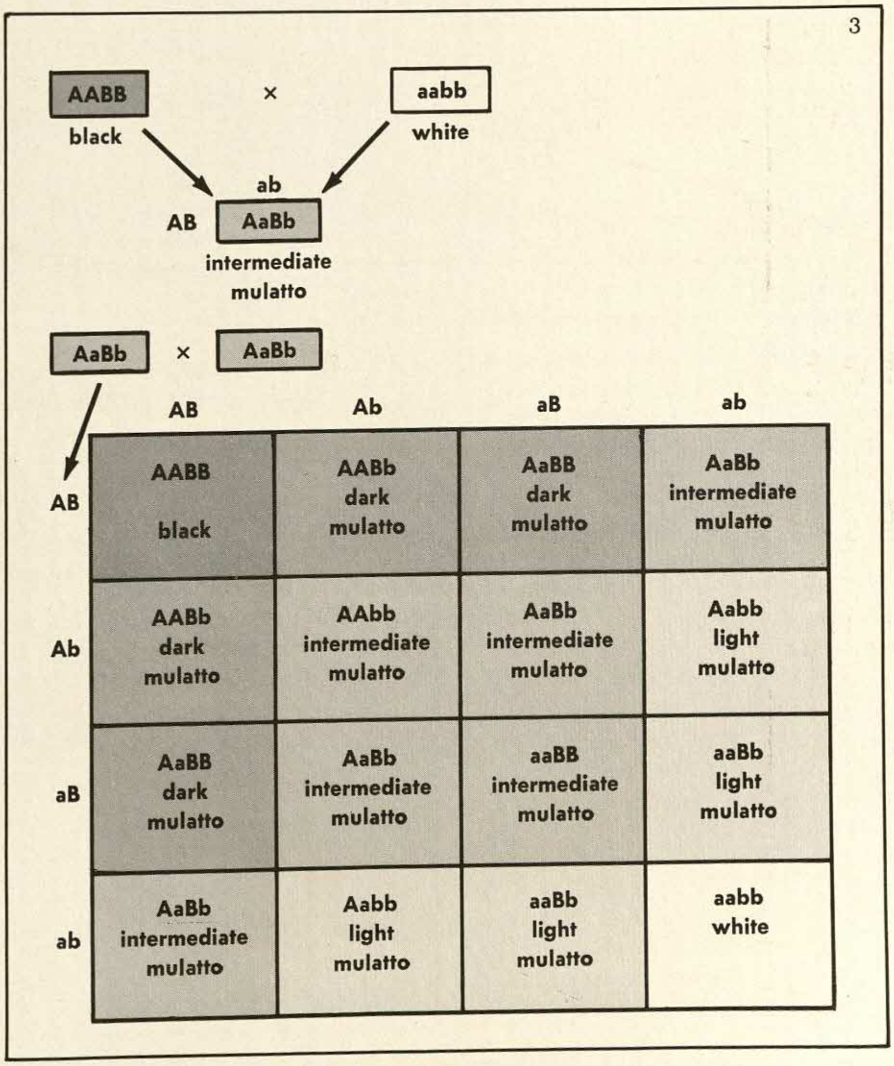
PENETRANCE AND EXPRESSIVITY

Many genes do not produce the same effect in all individuals. The manifestation of the genotype in traits or characteristics is called the phenotype. If all persons have the phenotype that corresponds to a gene that they carry, that gene is said to have 100 percent penetrance. If only some persons have the expected phenotype, the gene has a lower penetrance. Several cases of incomplete penetrance have been discussed above. In sex-influenced and sex-limited traits, the penetrance of genes is reduced in one sex, but not in the other. In the case of deaf-mutism, the penetrance of genes **D** and **E** is reduced by the presence of **ee** and **dd**, respectively.

Polydactyly—the condition of having extra fingers or toes—is due to a dominant gene, yet some persons with this gene have the normal number of digits. The expressivity of a gene is the way in which it expresses itself. Some persons with polydactyly have only one or two extra digits, while others have three or four or more. In some persons the extra digits are on the hands, in others on the feet, and in still others on both hands and feet.

MULTIPLE GENE INHERITANCE—A wide range of phenotypes is possible when a trait is controlled by several pairs of genes.

Here genes **A** and **B** are incompletely dominant to their alleles, **a** and **b.** The color of the individual depends on the proportion of genes for black (**A** and **B**) and genes for white (**a** and **b**).



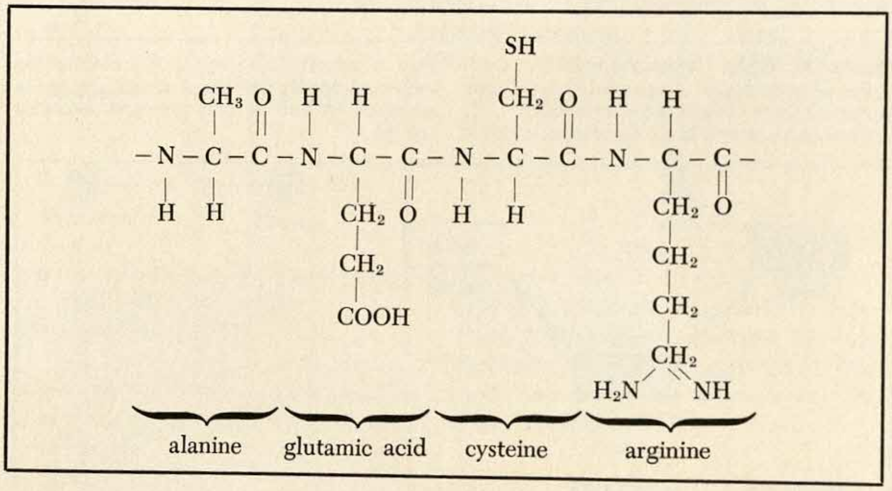
	AB	Ab	aB	ab
AB	AABB black	AABb dark mulatto	AaBB dark mulatto	AaBb intermediate mulatto
Ab	AABb dark mulatto	AAbb intermediate mulatto	AaBb intermediate mulatto	Aabb light mulatto
aB	AaBB dark mulatto	AaBb intermediate mulatto	aaBB intermediate mulatto	aaBb light mulatto
ab	AaBb intermediate mulatto	Aabb light mulatto	aaBb light mulatto	aabb white

PROTEINS | the boundary between chemistry and biology

Proteins are unique among organic compounds in their ability to function in so many important roles in living things. This characteristic is due to the great variety in composition and structure of proteins. Each protein has a primary structure, a secondary structure, and a tertiary structure.

PRIMARY STRUCTURE

The primary structure is the order of amino acids in the polypeptide chains of which the protein is composed. The amino acids are united in a linear order by condensation reactions between the carboxyl group of one amino acid and the amino group of another. The result is a long molecule consisting of the repetition of a set of three atoms, one atom of nitrogen and two atoms of carbon: $-N-C-C-$. One of the carbon atoms of each set bears the side chain of the amino acid. One of the great number of possible arrangements along a short segment of a polypeptide is:



Some of the side groups—such as the carboxyl group ($-COOH$) of glutamic acid, the amino group ($-NH_2$) of lysine, and the sulfhydryl ($-SH$) group of cysteine—are highly reactive, and by reacting with each other they contribute to the tertiary structure of proteins.

The 20 naturally occurring amino acids theoretically can occur in any order along the polypeptide chain, and the order is controlled by the genetic code in the deoxyribonucleic acid (DNA) in the nucleus. Any change in the order of the amino acids or the substitution of one amino acid for another may or may not make a profound change in the nature of the protein. A deletion or alteration in an inactive part of the molecule may have no noticeable effect on the organism. On the other hand, an error of only one amino acid—the substitution of valine for glutamic acid at one particular position in the hemoglobin molecule, for example—results in sickle-cell anemia, a serious disease that usually results in premature death.

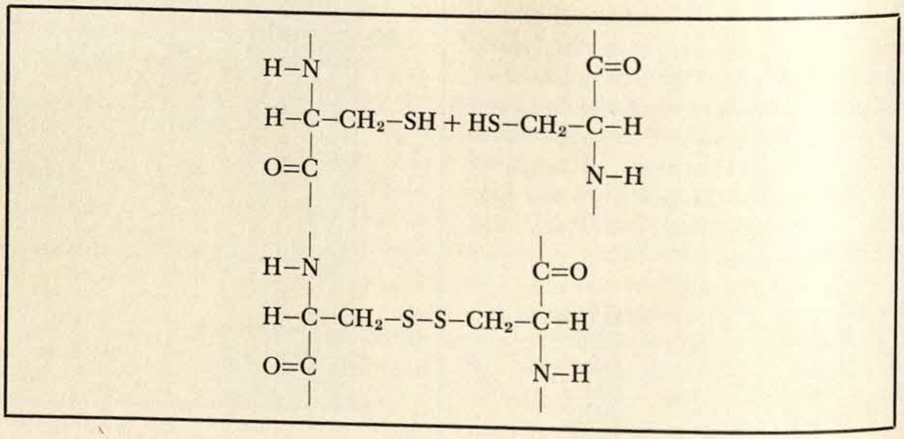
SECONDARY STRUCTURE

Although the amino acids occur in a linear order along the length of a polypeptide chain, the polypeptide does not exist as a straight molecule. The repeating $-N-C-C-$ backbone of the molecule is coiled into an alpha helix, the shape of which resembles a spring. One turn of the helix occurs for every 3.7 amino acids along the chain.

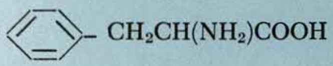
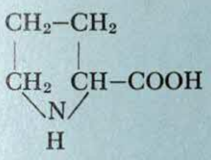
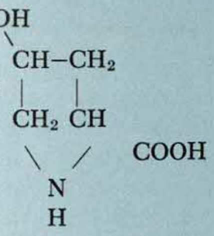
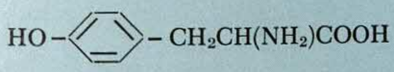
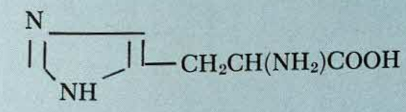
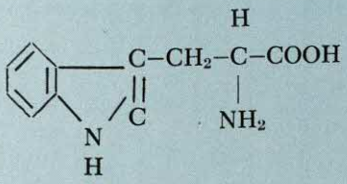
The structure of the alpha helix is held in place primarily by hydrogen bonds. These are weak bonds in which hydrogen atoms tend to share electrons with atoms of some other elements, usually oxygen or nitrogen. In the alpha helix, the $-\overset{\text{H}}{\overset{|}{\text{N}}}-$ group of one amino acid is brought into close proximity to the $-\overset{\text{O}}{\overset{\|}{\text{C}}}-$ group of the third amino acid away on the polypeptide chain, and these are held together by hydrogen bonds. An individual hydrogen bond is a weak bond, but the many hydrogen bonds in the polypeptide collectively are strong enough to maintain the alpha helix.

TERTIARY STRUCTURE

The alpha helix is folded further into a shape characteristic of the particular protein. This tertiary structure is maintained by several types of chemical bonds between the radicals or side groups of several amino acids along the length of the polypeptide. A common bond is the disulfide bridge formed by the reaction of the sulfhydryl groups of two cysteine radicals within a polypeptide:

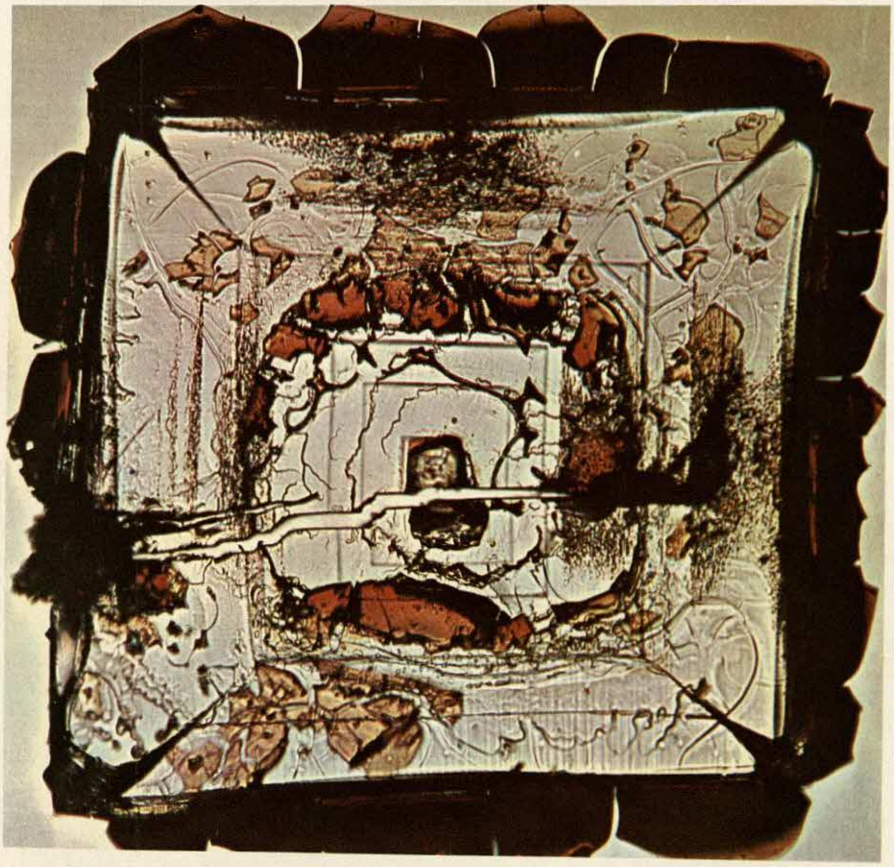


COMPOSITION OF THE MOST IMPORTANT PROTEINS—The table shows the composition of some of the chief proteins, given in percentages of amino acids. The proteins are of varied origin, and there is a great variety in their composition and structure.

Amino Acids	*Gelatin*	*Myosin*	*Oval-Bumin*	*Casein*	*Lactal-Bumin*
arginine $H_2NC(==NH)(CH_2)_3CH(NH_2)COOH$	7.9	5.7	5.1	3.5	1.0
glutamic acid $HOOC(CH_2)_2CH(NH_2)COOH$	10.0	19.8	14.5	18.5	11.3
aspartic acid $HOOCCH_2CH(NH_2)COOH$	5.8	8.2	8.0	7.0	16.1
glycine $CH_2(NH_2)COOH$	20.9	2.2	2.3	1.5	2.4
alanine $CH_3CH(NH_2)COOH$	8.8	7.9	5.6	2.8	1.7
valine $(CH_3)_2CHCH(NH_2)COOH$	2.2	4.1	6.0	4.8	3.9
leucine $(CH_3)_2CHCH_2CH(NH_2)COOH$	2.9	9.2	7.9	6.9	9.9
isoleucine $CH_3CH_2CH(CH_3)CH(NH_2)COOH$	1.5	4.1	6.0	4.9	5.9
phenylalanine 	2.0	6.1	6.9	4.1	4.0
serine $HOCH_2CH(NH_2)COOH$	3.5	3.8	6.8	5.3	4.0
threonine $CH_3CH(OH)CH(NH_2)COOH$	1.9	3.7	3.4	3.6	4.7
cysteine $HSCH_2CH(NH_2)COOH$	0.0	0.7	1.6	0.4	5.4
proline 	13.8	0.7	3.0	7.0	1.7
hydroxyproline 	12.2	0.0	0.0	0.0	0.0
tyrosine 	0.3	10.0	3.3	6.6	4.9
lysine $H_2N(CH_2)_4CH(NH_2)COOH$	4.7	9.0	5.5	8.2	10.0
methionine $H_3CS(CH_2)_2CH(NH_2)COOH$	0.8	1.5	1.6	2.4	0.8
histidine 	0.7	2.0	2.1	2.6	2.5
tryptophan 	0.0	0.0	1.1	1.8	6.4
Total	99.9	98.7	90.7	91.9	96.6

2

a



ALBUMIN OF THE BLOOD—One of the most important of the albumins is serum albumin. This protein has a molecular weight of about 69,000 and accounts for a high percentage of the protein content of serum. Used in the pharmaceutical industry, it is prepared pure. Illustration 2a shows an albumin crystal seen through a microscope in polarized light. (60 X) Illustration 2b shows the pure protein in bulk.

b

The larger amino acid formed by the reaction of two cysteine molecules is cystine.

Another type of bond that holds the tertiary structure in place is the electrostatic bond between acid and basic groups such as the carboxyl group of glutamic acid and the amino group of arginine. Two weak forces contribute to the stability of the tertiary structure. These are the hydrogen bond and van der Waals forces. The latter are attractive forces between neutral radicals such as the methyl group ($-CH_3$) of alanine.

Most proteins consist of a few polypeptide molecules joined by the same bonding that maintains the tertiary structure.

There are two general types of proteins based on tertiary structure. Globular proteins are folded into an approximately spherical shape or other compact shape. Fibrous proteins are more elongated, usually having one diameter much longer than the others.

Most enzymes are globular proteins, and their specificity depends partially on the shape of the molecule—because the reaction with a substrate depends on a good "lock-and-key" fit between the enzyme molecule and the substrate molecule. This helps to explain why changes in the primary structure may or may not alter the ability of the protein to function properly. If, for example, a cysteine ordinarily involved in a disulfide bridge were replaced by another amino acid, the bridge could not be formed; this would result in an important alteration in the overall shape of the protein. A change involving another amino acid in a different position might not have any effect on the shape of the molecule.

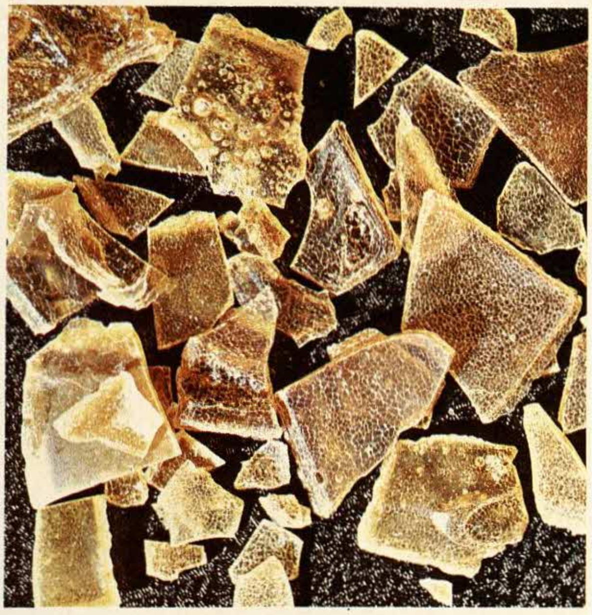
Fibrous proteins have fewer bonds maintaining the tertiary structure than do globular proteins. For this reason, more radicals are available to react with other molecules of the same protein; consequently, fibrous proteins tend to form more viscous solutions than do globular proteins. Many of them are insoluble in water. Some fibrous proteins are the fibrin that forms blood clots that seal wounds, the collagen fibers in the ground substance of connective tissue, and the keratin of hair and wool. Keratin has a large number of disulfide bridges. A permanent wave basically involves two steps: the breaking of the disulfide bonds, and then the reforming of new disulfide bonds while the hair is held in the desired position. Chemically, wool keratin is not unlike hair, feathers, and horn. It is rich in the amino acid cysteine.

3

OVALBUMIN—Albumins contain many amino acids, but their molecules are characterized by a low content or absence of glycine and a high cysteine and methionine content. Ovalbumin (molecular weight about 40,000) occurs in egg white and is prepared in large quantities for use in the food industry and in the photographic industry as a sensitive emulsion; it is also used in tanning. Illustration 3a is a microphotograph taken in polarized light of a crystal of ovalbumin. (60 X) Several ovalbumin crystals are shown in Illustration 3b.

a

b

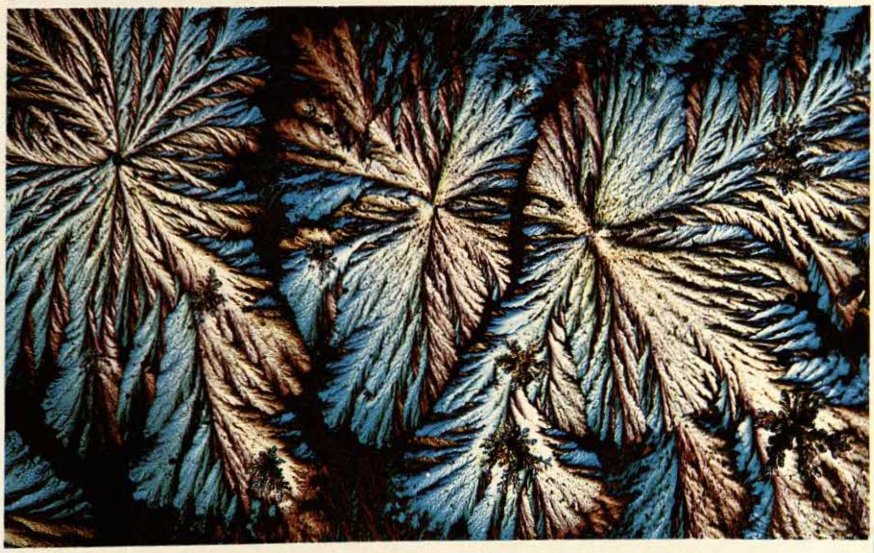


4

CASEIN—Casein is one of the most important of the conjugated proteins. It contains phosphoric acid as a prosthetic group bound to the amino acid serine; phosphorus accounts for about 0.9 percent of its molecular weight, which varies from 19,800 to 27,000. It accounts for about 80 percent of the protein content of milk. Casein is of great importance in the food industry as a component of cheese, although this is by no means its only use; it is also used in pharmacology as a source of amino acids and in the paint industry as a binder and emulsifier. Most important of its industrial uses, perhaps, is its use as raw material for plastic materials, particularly in the manufacture of galalith. It is also used in the manufacture of synthetic wools. Illustration 4a shows the purified protein; Illustration 4b shows it crystallized from an alkaline solution. The latter photograph was taken through a microscope in polarized light. (60 X)

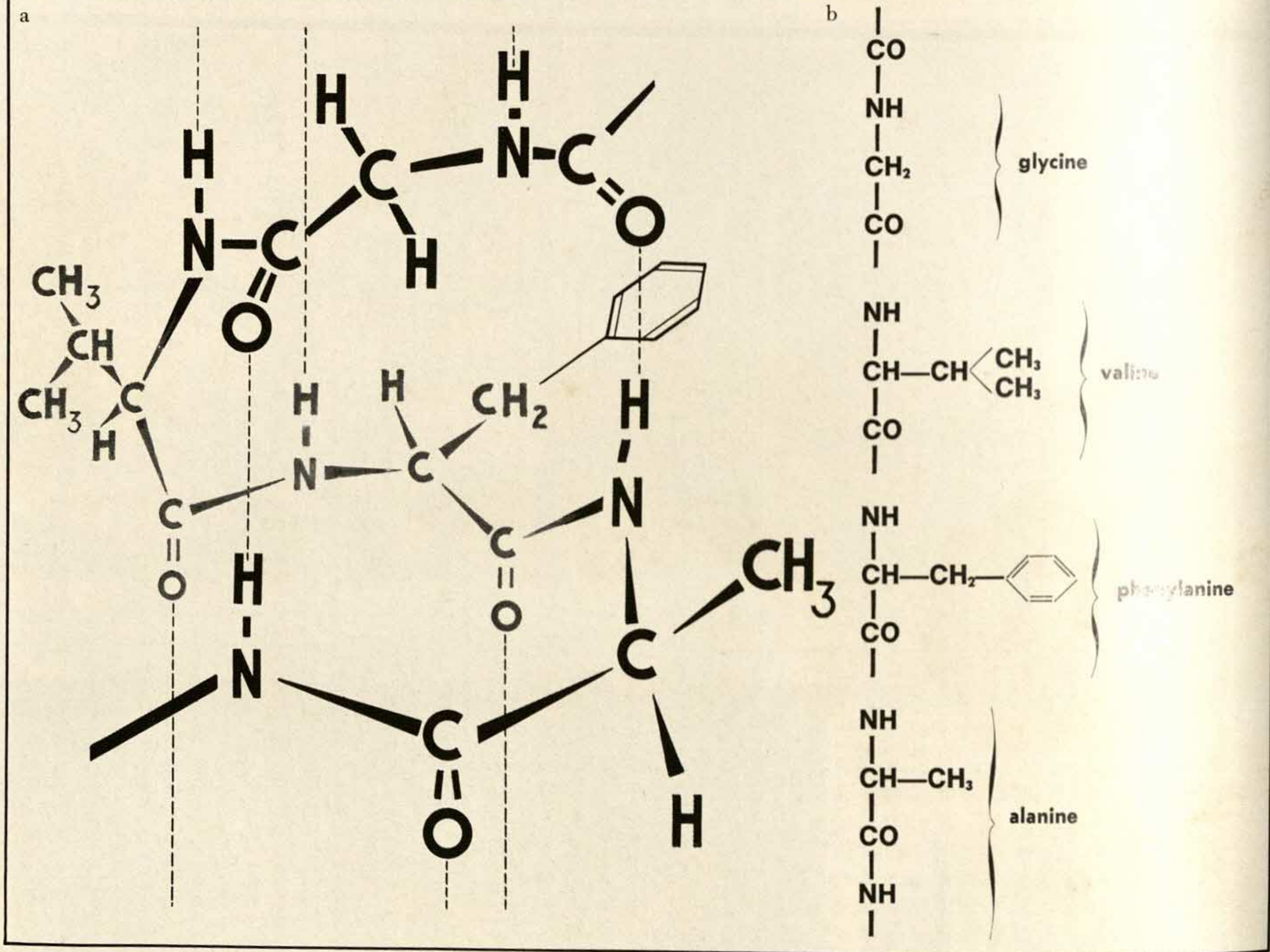
a

b



5

THE α-HELIX — The secondary structure of proteins (that is, the shape that the protein chain takes in space) has been shown by recent research to be, in most cases, a helix called an α-helix (Illustration 5a). The dotted lines represent the hydrogen bonds that keep the construction stable. The side chains of the amino acids face outward from the helix. Illustration 5b shows a plane projection of the same succession of amino acids.



DENATURING OF PROTEINS

The application of heat causes the "unwinding" of the alpha helix. This destruction of the secondary structure of the protein also destroys its tertiary structure and therefore interferes with its functioning. It is called denaturing, and usually it is irreversible. The exact temperature necessary to achieve this effect varies with the protein. Enzymes are particularly sensitive to heat. Death of organisms exposed to high temperatures may be due to heat denaturing of their enzymes.

An easily observed example of irreversible heat denaturing is the effect of boiling on the white of an egg. The raw egg white, which consists of the protein ovalbumin, has a fluid consistency and is semitransparent. Boiling solidifies the ovalbumin and makes it opaque. Cooling the boiled egg does not restore it to its original condition.

CLASSIFICATION OF PROTEINS

Proteins are classified as simple proteins or conjugated proteins, each category comprising a number of groups distinguished from one another by given physical and chemical characteristics. Simple proteins are synthesized exclusively from amino acids. They can be divided into seven basic groups that vary in their solubilities in water and other solvents.

1. *Albumins* are neutral and are soluble in water and dilute salt solutions. They are precipitated by neutral salts, though only when the solution is virtually saturated with the salt. They coagulate when heated. Included in this group are ovalbumin (the chief constituent of egg white), lactalbumin (obtained from the whey of milk), and a few proteins of vegetable origin, some of which (ricin, obtained from the castor-oil plant, and legumelin, from peas) are highly toxic.

2. *Globulins* are weakly acid and insoluble in water at neutral pH, although soluble in acid or alkaline solutions. The

group includes serum globulin in the blood, myosin (a contractile agent of muscles), edestin (from hemp seeds), and the α-, β-, γ-globulins from whey.

3. *Prolamins* or *gliadins* are insoluble in water and absolute alcohol but are soluble in 70 to 80 percent alcohol. They have a high proline and glutamic acid content. Examples are gliadin (derived from wheat), zein (from corn), and hordein (from barley).

4. *Glutelins* are readily soluble in dilute acids and alkalies but are insoluble in neutral solvents. Examples are glutenin (from wheat) and oryzenin (from rice).

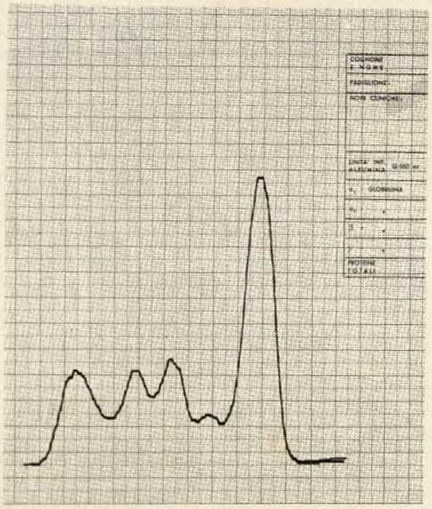
5. *Histones* are soluble in water and insoluble in dilute solutions of ammonia. They are basic in character because of their high diamino acid content. They are included in the globin of hemoglobin and are combined with nucleic acids to form nucleohistones.

6. *Protamines*, like histones, are markedly basic in character. They are soluble in water and form salts with acids. Their molecular weight is relatively low. When hydrolyzed they produce mostly basic amino acids (arginine, lysine, histidine). They occur in fish and include clupeine (herring), salmine (salmon), and sturine (sturgeon). Some protamines have recently been brought into use in medicine; an association of protamine and insulin, for example, is used in the treatment of diabetes.

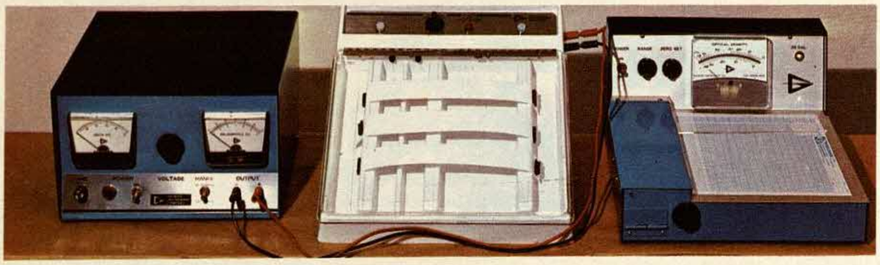
7

ELECTROPHORESIS—One method used to analyze accurately mixtures of proteins, even when they belong to the same group and, therefore, closely resemble each other, is electrophoresis, which is capable of detecting very small quantities of substances. The process may take various forms, but for analytical purposes it is common to use zonal electrophoresis on strips of paper or cellulose acetate; these substances act as a support for the buffered solution containing the mixture of proteins to be separated and analyzed. When an electric current is run through the solution on the strips, substances in solution migrate to the anode (positive pole) if they have negative charges, and to the cathode (negative pole) if they have positive charges. Because different substances move at different speeds, it is possible to stop the migration when the substances are distributed along the strip. Then the separated proteins are identified. Illustration 7a shows an electrophoretic unit, complete with feeder, electrophoretic cell, and a machine for reading the electrophoretic strips. Illustration 7b is a graph obtained from the analysis of a blood serum: the five peaks correspond to albumin and α_1-, α_2-, β-, and γ- globulins.

b



a



THE TERTIARY STRUCTURE OF PROTEINS—The α-helix of most proteins is bent into a characteristic shape called the tertiary structure. Shown here is a globulin, a protein in which the tertiary structure assumes a nearly spherical shape.

6

7. *Scleroproteins* are fibrous proteins and are insoluble in aqueous solutions. They are widespread in the animal kingdom, where their functions involve protection and support. The keratins, for example, are the basic constituents of hair, horn, feathers, and nails. They contain large quantities of the sulfur-containing amino acid cysteine. Other fibrous proteins include collagen, which yields gelatin on boiling and occurs in bones, cartilage, and other connective tissue; elastin, which is found in elastic tissue; fibrin, which clots blood; and fibroin, one of the proteins in silk.

CONJUGATED PROTEINS

Conjugated proteins are proteins associated with other compounds. The casein of milk is a phosphoprotein, a protein combined with phosphoric acids; cheese consists mostly of coagulated casein. Glycoproteins are combinations of proteins with carbohydrates. Mucin, a constituent of saliva, is a glycoprotein. The nucleoproteins consist of proteins associated with nucleic acids. Deoxyribonucleoprotein is present in the chromosomes and contains the genetic material; ribonucleoprotein is a major constituent of the ribosomes in the cytoplasm. Synthesis of proteins occurs on the ribosomes.

If the nonprotein part of the molecule is known to have a biological function, it is referred to as the prosthetic group. If the prosthetic group is colored, the conjugated protein that contains it will also be colored. Chromoproteins, compounds of a protein with a metal-containing pigment or a carotenoid, are colored. For example, hemoglobin, the main part of the red cells of blood, consists of the protein globin and the colored heme, the four molecules of which contain one iron atom each.

RESISTANCE AND IMMUNITY | a complex defense mechanism

The human body is like a fortress under siege. It does not permit many microorganisms to enter its blood or its tissues, and it does not suffer passively the attacks of those microorganisms that do manage to penetrate its tissues. It has at its disposal various defense mechanisms that prevent organisms from reaching internal tissues and that kill or inactivate the organisms or destroy their toxic products.

RESISTANCE

Resistance includes all the nonspecific mechanisms of defense that function equally well against many different species of microorganism. Perhaps the most obvious of these is the skin that covers most of the body, and the mucous membranes that line those body cavities that have openings to the outside. Perspiration contains antimicrobial substances and thus has a protective function on the skin. Mucus is a slimy substance secreted by most of the mucous membranes of the body. Microorganisms that enter into body cavities are likely to become trapped in it and then expelled. Coughing or sneezing rid the body of organisms this way. Lysozyme, which has a mild antibacterial action, is present in tears and on the skin and mucous membranes; and urine protects the urogenital openings by its flushing action.

As long as the skin and the mucous membranes remain undamaged, most organisms cannot penetrate them. But if by reason of mechanical injury or the effects of malnutrition these tissues should be broken, then the inner, susceptible tissues are exposed to the bacteria and other microorganisms that invariably are present on the skin and mucous membranes.

Once microorganisms have invaded the body, certain types of white blood cells, called phagocytes, are carried by the blood to the site of infection. Here they ingest the organisms by an amoeboid action called phagocytosis. Within the phagocytes, the microorganisms are digested and thus disposed of. Phagocytes can attack not only those foreign organisms that have reached the blood, but because of their amoeboid characteristics, phagocytes move between the cells of the capillary walls and penetrate into tissues; here they can ingest additional microorganisms.

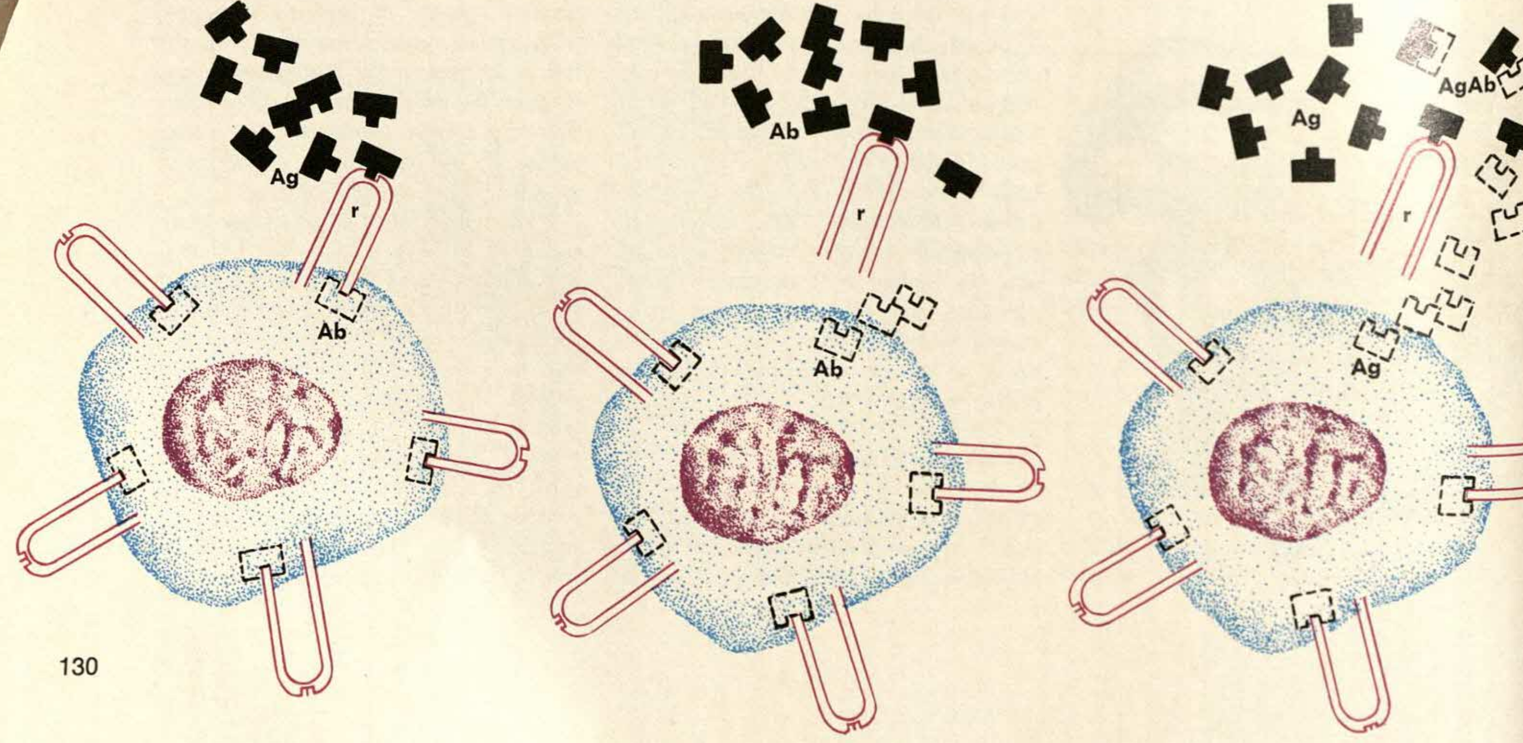
The forming of a blood clot at the site of the break is another mechanism of resistance. Fibrin, a fibrous protein of the blood, is formed in the vicinity of the break. The long molecules form a meshwork that prevents the entrance of more microorganisms into the blood. This prevents spreading of the infection throughout the body. Some phagocytes also become caught in the clot, and they ingest those microorganisms that still remain in the area. When all the invading organisms are killed, the wound heals, and the clot, or scab, falls off.

IMMUNITY

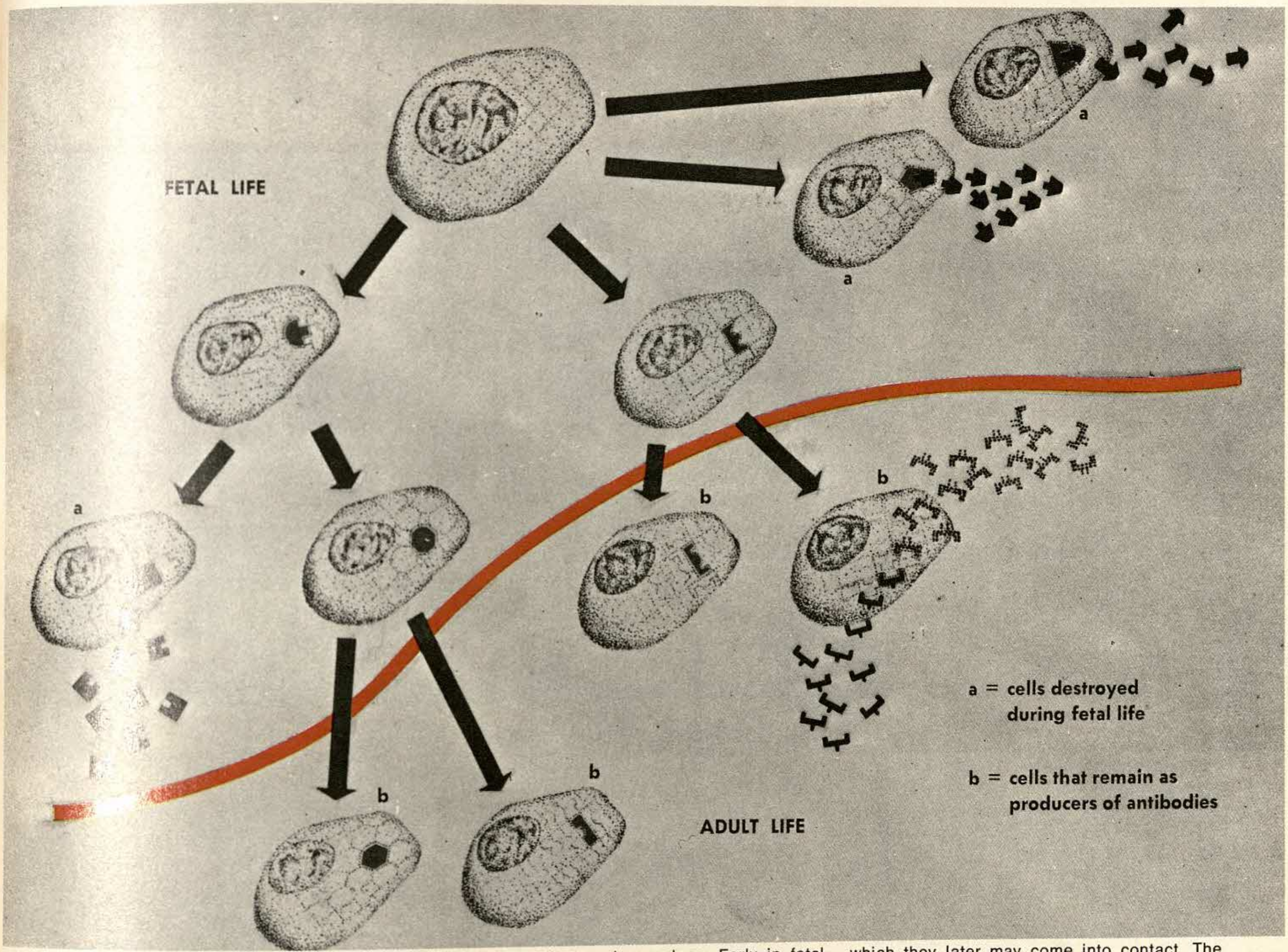
If all the mechanisms of resistance should fail, the body has still another line of defense. It produces antibodies that are specific for antigens of particular invading organisms. An antigen is any

SZILARD'S THEORY — This theory, the genetic derepression theory of antibody formation, states that certain cells of the body contain all the information needed to produce antibodies **Ab** of any type. In the absence of a particular antigen **Ag**, the enzymes necessary for the manufacture of that antibody are blocked by an inhibitor **r**. Contact with the antigen removes the inhibition, which enables the enzymes to start producing specific antibodies. The antibodies unite with the antigen, forming an antigen-antibody complex that renders the antigen harmless.

1



2


FETAL LIFE
a
a
a
b
b
b
b
ADULT LIFE
a = cells destroyed during fetal life
b = cells that remain as producers of antibodies

BURNET'S THEORY—This theory, the clonal selection theory of antibody formation, states that during the development of the fetus, cells are produced that are capable of manufacturing antibodies, but each cell can produce only one type of antibody. All the descendants of a single cell comprise a clone. Early in fetal life, the cells producing antibodies that react with substances formed by the fetus are destroyed. In this way, after birth, the organism has cells selected to produce antibodies that are adapted to react to foreign antigens with which they later may come into contact. The red line separates the period of fetal life, characterized by immunological immaturity (above), from the period that starts after birth (below). A defective thymus gland may lead to disastrous immunologic deficiency.

protein foreign to the body, and some microorganisms bear several such proteins on their surfaces. Some antigens are toxins that are released by bacteria, and that can harm tissues even if the bacteria are not present.

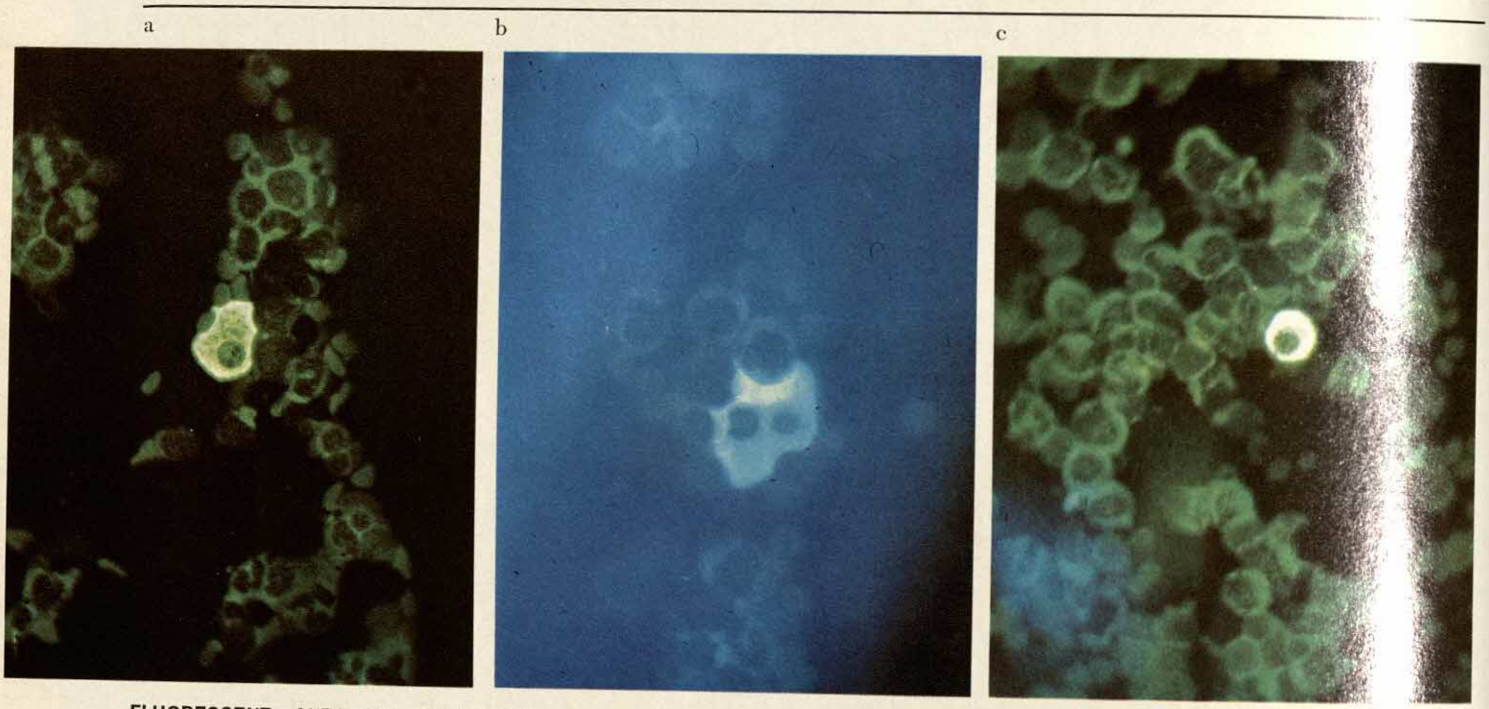
A given antibody is effective against only one type of antigen. An antibody specific for tetanus toxin is not effective against the organisms of typhoid or cholera, and one for typhoid does not protect against tetanus. Because a certain amount of time is required for the body to form specific antibodies after the first exposure to an antigen, the recovery from the initial infection usually is not due to the antibodies that are produced then. But the antibodies do confer immunity against later infections by the same organism; often the immunity is lifelong.

Antibodies are manufactured by plasma cells, another type of white blood cell. When an antigen is present in the body, the plasma cells are stimulated to produce antibodies specific for the antigen. The first exposure to an antigen results in the production of a relatively low concentration of the antibody. When the infection is no longer present, the antibody concentration falls very low, but subsequent exposures produce high concentrations that are achieved so quickly that usually no pathological symptoms develop.

ACTIVE IMMUNITY

Active immunity is the immunity that develops when an individual forms his own antibodies against antigens. It may be acquired naturally, as when a person contracts a disease, however mild. Active natural immunity often is lifelong. This is why some diseases traditionally are called children's diseases. Adults are ca-

3



FLUORESCENT ANTIBODY TECHNIQUE — These three photographs show preparations from human bone marrow treated with fluorescent antibodies and viewed under an ultraviolet microscope. The antibody is made fluorescent by combining it with a fluorescent stain. When the antibody reacts with an antigen, it forms an antigen-antibody fluorescent stain that glows under ultraviolet light.

pable of contracting these diseases if they have not previously had them, but most adults became immune to them in childhood.

Active immunity may also be acquired artificially by immunization. An immunization is an injection of a small amount of living or dead organisms, or inactivated toxins, into the body, which then forms its antibodies in response to their presence. Because of the danger of contracting a serious disease from live organisms, they usually are attenuated in some manner. The smallpox organisms, for instance, are grown for several generations in cattle; during this time they lose much of their virulence. If the microorganisms produce toxins, injections of their toxins alone can confer immunity just as well as injections of the living organisms. Because the toxins often are extremely dangerous, they, too, must be treated before they can be used. They are inactivated by heat treatments or formaldehyde and called toxoids. Active artificial immunity can last for years.

The word vaccination derives from the Latin word *vacca,* which means "cow." The first vaccinations were performed by the English physician Edward Jenner in 1796, who noticed that milkmaids who had suffered the relatively mild disease cowpox were immune from the dreaded smallpox. By rubbing small quantities of the material from the smallpox pustules into the skin of persons who had had neither smallpox nor cowpox, Jenner was able to immunize them against both diseases.

PASSIVE IMMUNITY

A person may become immune to a disease without forming his own antibodies. A newborn baby often is immune to several diseases, because it has received antibodies from its mother before birth. This is called passive natural immunity, and it usually lasts for only a few months.

A person may also get passive artificial immunity by receiving injections of serum from another person or animal that has had the disease or that has received injections of the causative organism. Such serum is called immune serum, and it confers immunity for a relatively short time, usually a few weeks. Immune serum is used for protection when active immunization is not available or feasible. It is also used therapeutically after a person has contracted certain diseases; if he does not have an adequate supply of his own antibodies, the added ones aid in his recovery.

One disadvantage of receiving serum from animals is that the serum contains proteins foreign to the human body. The person receiving them may be allergic to them, and his reaction to them may be more serious than the disease that the serum was meant to cure. Therefore, nearly all immune serums in present use are obtained from human donors. Because of the risk of transmitting viral hepatitis with human blood products, however, it is now customary to use gamma globulin prepared by chemical treatment from pooled human plasma.

HORMONES

chemical messengers

Orderly integration of the numerous chemical processes occurring in the animal body is a function shared by two organ systems: the endocrine system and the nervous system. The endocrine system consists in part of ductless glands that produce hormones and secrete them directly into the bloodstream, which transports them to other parts of the body where they exert their effect. The nervous system conducts impulses of an electrical nature along nerve cells. The two systems are not completely distinct, however; nerve cells produce neurohormones and neurohumors, both of which have hormonal properties. Each system exerts some effect on the other.

Hormones have been detected in nearly all groups of animals. Not only do they maintain a healthy state, but they control growth and reproduction as well. In insects and some other groups, metamorphosis, a change to drastically different stages of the life cycle, is controlled by hormones.

HORMONES, NEUROHORMONES, AND NEUROHUMORS

Chemically, hormones do not fall into a single group, but most of them are either proteins, polypeptides, or steroids. In the older, more traditional sense, hormones are the products of the ductless glands, each of which manufactures one or more hormones. The hormones are called chemical messengers because they are secreted into the bloodstream and carried to other parts of the body, often parts far distant from the organ of synthesis, where they exert their effect. Many hormones have only one or a few rather specific effects on a single or a few tissues or organs. Some, like the growth hormone, have diverse effects throughout the body. The ductless glands of the human body include the hypophysis (pituitary gland, sometimes also called the master gland because it secretes so many hormones that affect directly or indirectly nearly all of the processes of the body); the pancreas; a variety of small glands in the walls of the digestive system; the thyroid gland, parathyroid glands, adrenal glands, and the ovaries and testes.

Neurohormones are compounds produced by nerve cells, but otherwise they have the traditional characteristics of hormones. They are transported by the circulatory system to the tissues or organs that they affect. Oxytocin and vasopressin are neurohormones synthesized in special neurosecretory cells in the hypothalamus of the brains of vertebrates. These cells release their neurohormones to the hypophysis, from which they are transported like other hormones by the bloodstream. A variety of neurohormones has been discovered in invertebrates. Much research has been done on those neurohormones that control the molting and metamorphosis of insects.

Neurohumors differ from other hormones in exerting their effects near their site of synthesis rather than being carried to distant organs by the blood. Acetylcholine and noradrenalin (norepinephrine or sympathin) are secreted by nerve endings and diffuse across the minute synapses to adjacent nerve cells. Their function is the transmission of nerve impulses across the synapses. The noradrenalin secreted by nerve cells is identical with or very similar to that produced by the adrenal glands.

THE MECHANISM OF HORMONAL ACTION

In view of the fact that hormones have different chemical structures, it is not surprising that they perform their functions in different ways. At least four different mechanisms of hormonal action have been discovered. Some hormones may act in more than one way.

No chemical reaction can occur without a supply of compounds to react with each other. Some hormones exert their effect on reactions by controlling the entrance of substances into the cell. Insulin, for example, increases the permeability of the cell membrane to glucose, thus increasing the amount of this sugar that enters the cell and making it available for chemical reactions.

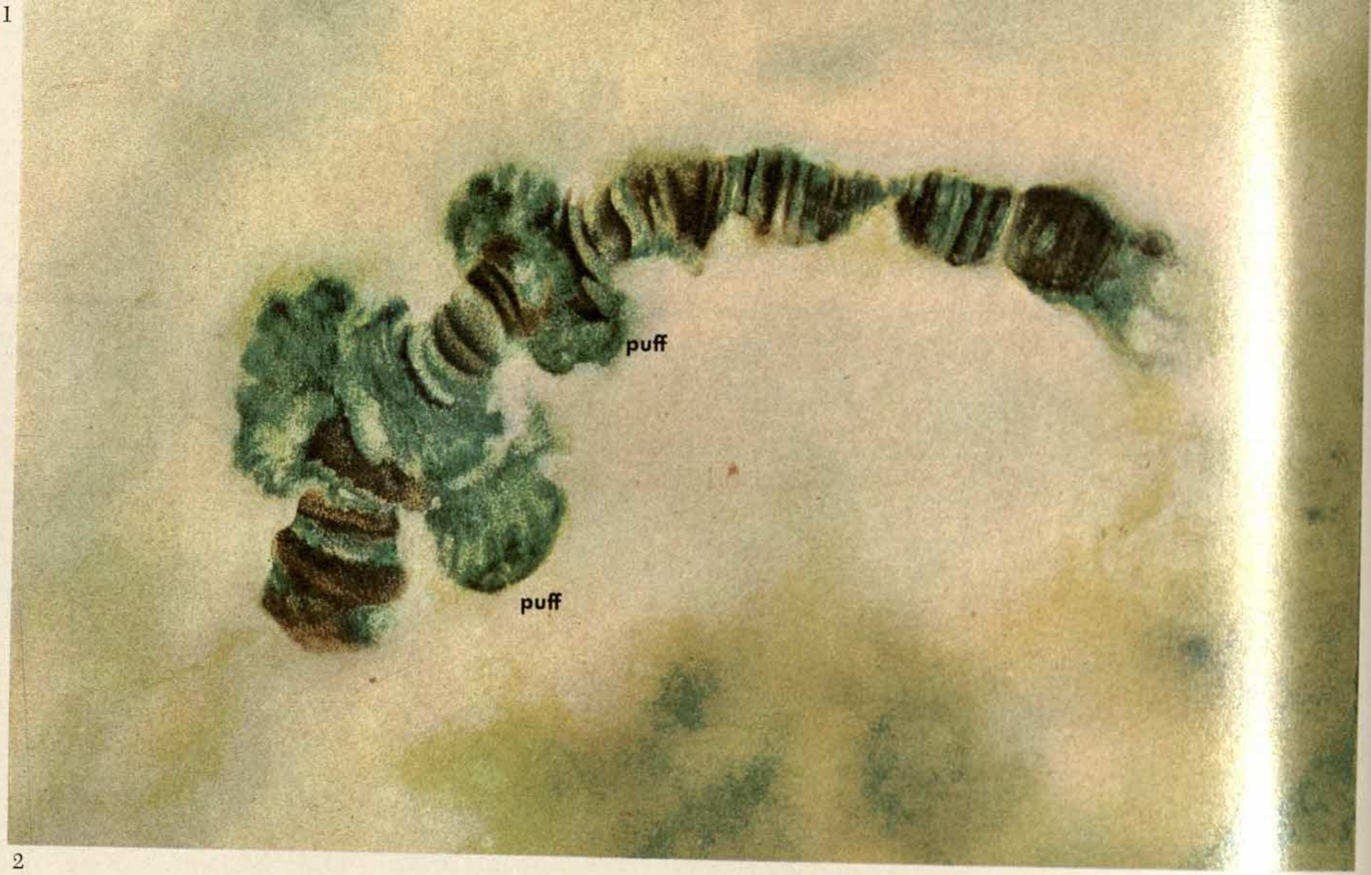
Most chemical reactions in living things are catalyzed by enzymes, and some hormones affect enzyme systems directly. Adrenaline, glucagon, and estradiol act by converting inactive forms of enzymes to active ones.

Another mechanism of hormonal action involves the activation or suppression of the genes that carry the genetic code for the synthesis of enzyme molecules. By turning the genes "on" or "off," the hormones determine whether a particular enzymatically controlled reaction will or will not occur. Ecdysone, the molting hormone of some insects, produces a visible effect on certain chromosomes. The chromosomes in the salivary glands of the fruit fly are so large that when they are stained a distinctive pattern of bands can be observed. It is on these bands that the genes reside, and the exact locations of many genes have been determined. The introduction of ecdysone into the cells of the salivary gland produces swellings or puffs on the chromosomes. It is believed that ecdysone removes the protein histone from the gene that is to be activated; this exposes the DNA and permits it to swell outward, forming a puff. The exposed DNA then acts as a template for the formation of messenger RNA, which carries the genetic code to the cytoplasm where the enzyme coded for is synthesized. That the RNA actually is formed within the puffs has been demonstrated by supplying cells with radioactive precursors of RNA; within a short time the puffs become highly radioactive.

At least one vertebrate hormone, cortisone, acts like ecdysone by affecting gene action. It seems likely that other hormones will be discovered to act in this manner, each hormone affecting only certain genes in certain tissues or organs.

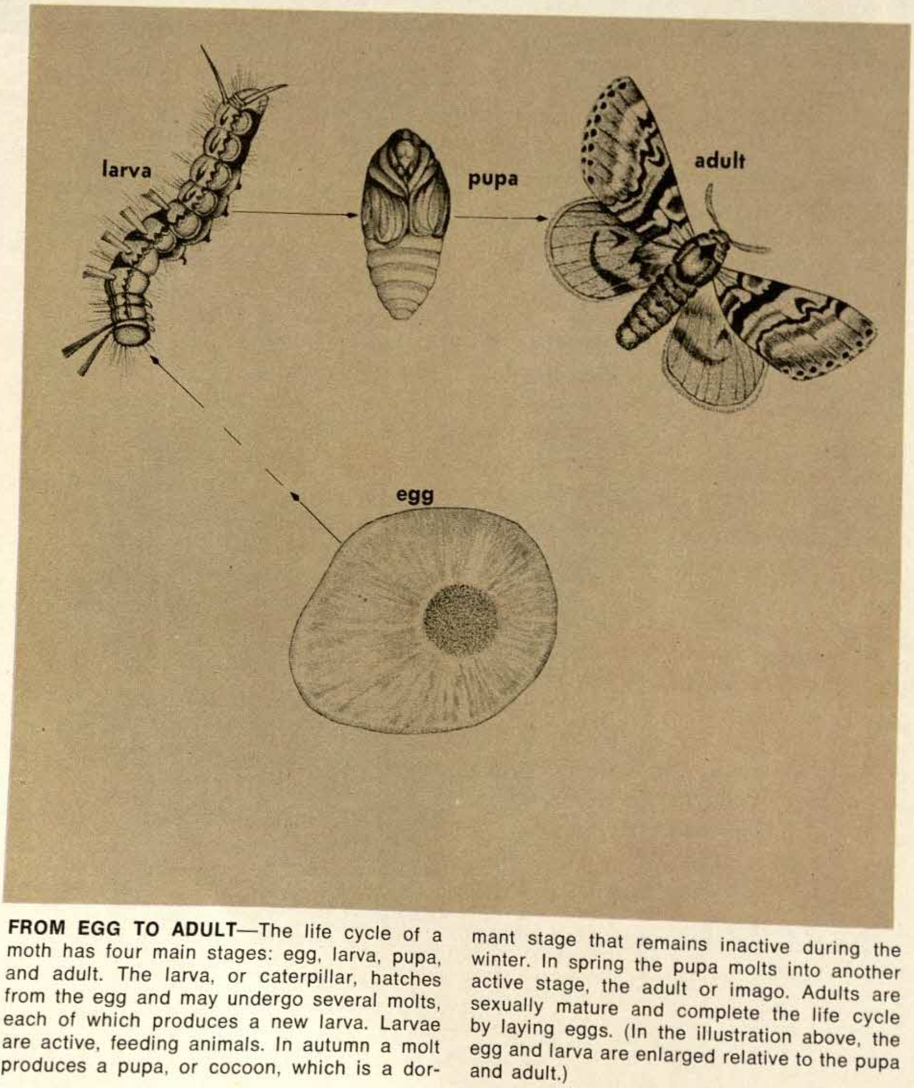
Synthesis of enzymes depends not only on the formation of messenger RNA in the nucleus, but also on the assembly of amino acids into proteins on the surfaces of the ribosomes in the cytoplasm. Evidence exists that at least one hormone, the growth hormone, controls cellular metabolism by exerting its effect on the ribosomal synthesis of enzymes.

1



A CHROMOSOME WITH TWO PUFFS—This chromosome shows the characteristic banding of giant chromosomes. The brown areas are rich in DNA. The green areas in the main body of the chromosome are predominantly protein, but the puffs consist mostly of messenger RNA (illustration 1).

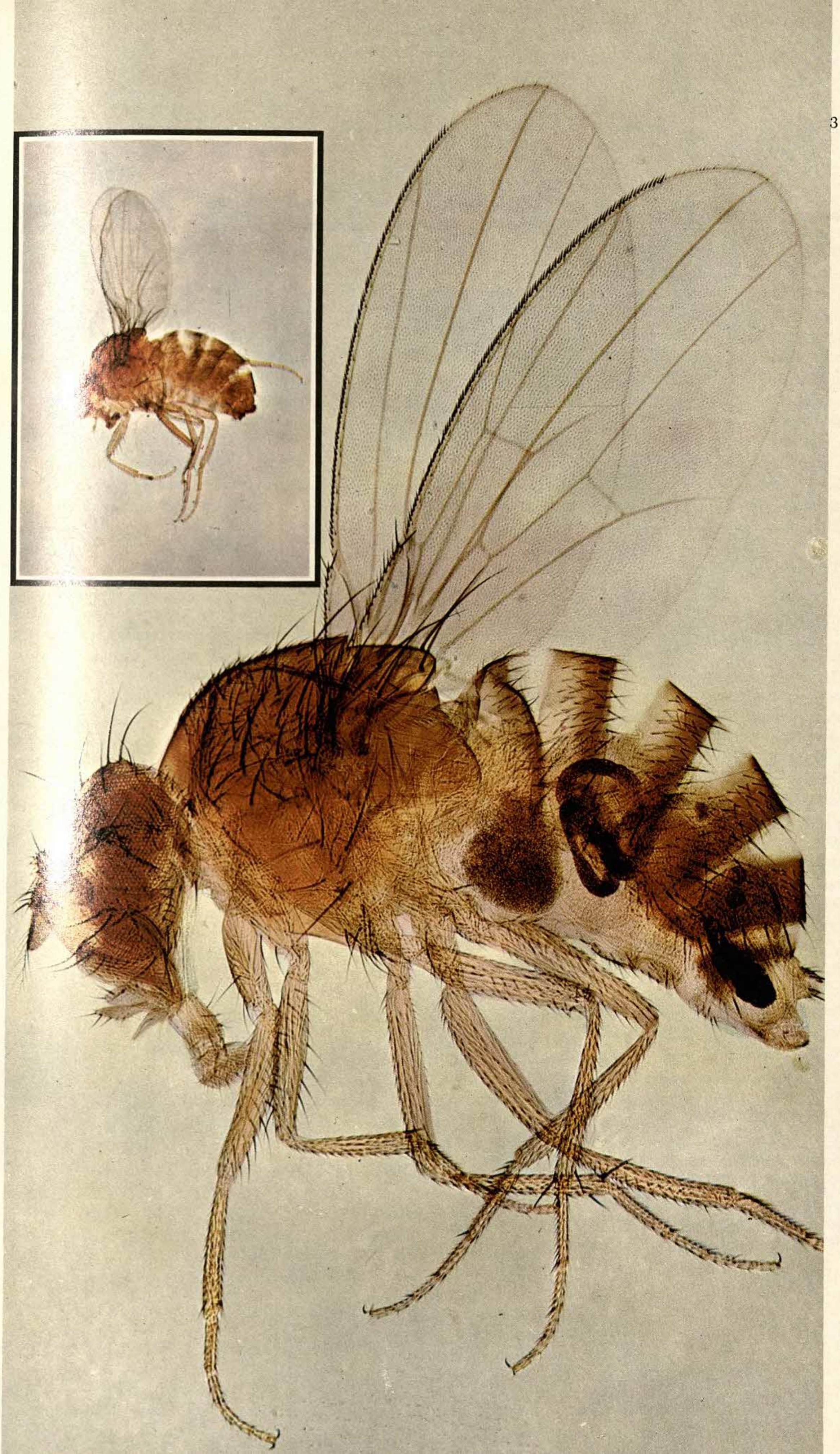
2



FROM EGG TO ADULT—The life cycle of a moth has four main stages: egg, larva, pupa, and adult. The larva, or caterpillar, hatches from the egg and may undergo several molts, each of which produces a new larva. Larvae are active, feeding animals. In autumn a molt produces a pupa, or cocoon, which is a dormant stage that remains inactive during the winter. In spring the pupa molts into another active stage, the adult or imago. Adults are sexually mature and complete the life cycle by laying eggs. (In the illustration above, the egg and larva are enlarged relative to the pupa and adult.)

FEMALE FRUIT FLY—The nuclei in the cells of the salivary glands of the larvae of several insects including the fruit fly (*Drosophila*) have giant banded chromosomes that can be observed under the relatively low magnifications of the light microscope. Many years of genetic research have revealed that the genes reside in these bands, and that each gene is associated with a specific band. Because the chromosomes of the fruit fly have been described in great detail, these insects are valuable for research on the effects of hormones on the genetic system of the cell.

Occasionally certain localized areas of the chromosomes exhibit swellings called puffs. It is now known that these regions are those in which genes are actively producing messenger RNA, the substance that moves to the cytoplasm, where it directs the synthesis of proteins on the surface of the ribosomes. Activation of some genes is caused by the presence in the nucleus of ecdysone, the molting hormone. Ecdysone is secreted by the prothoracic glands and travels to other parts of the body where it activates genes involved in the molting of the insect. A given hormone activates only certain genes in certain cells, but its action may affect other hormones or be affected by other hormones. In the larva, the presence of sufficient quantities of the juvenile hormone produced in the corpora allata of the insect brain causes the production of another larva at the completion of a molt. If there is little juvenile hormone present, the molt produces a pupa (50 X). The insert at upper left in Illustration 3 shows a male fruit fly. (13 X)



3

ENZYMES | catalysts of biochemical reactions

One way in which living things differ from their nonliving environment is in their chemical composition. The complex organic compounds of which organisms are composed are not found in the nonliving world except as the products of the metabolism of organisms. The synthesis of these many organic compounds in nature is theoretically possible outside of living cells, but the extreme slowness at which it could proceed practically prohibits the possibility. Living cells, however, contain enzymes—catalysts that greatly accelerate the rates of these reactions. Without enzymes, life as it exists today on the Earth would not be possible.

CHARACTERISTICS OF ENZYMES

All enzymes are proteins, but many of them have a nonprotein portion as well. In some enzymes, the nonprotein portion —the coenzyme—separates readily from the protein portion, the apoenzyme. The entire enzyme is the holoenzyme. Some vitamins—such as thiamin, riboflavin, and niacin—are parts of coenzymes, which determine the type of reaction that is catalyzed. Cocarboxylase, which contains thiamin, catalyzes the removal of carbon dioxide from some organic compounds. The several coenzymes of which riboflavin and niacin are a part transfer hydrogen from one compound to another. The apoenzyme is responsible for the specificity of the enzyme; it determines what substrate will be acted on.

Some enzymes consist of two parts that are not readily separated. These enzymes are the conjugated proteins, and their nonprotein portion is called a prosthetic group. One of the best-known conjugated proteins is hemoglobin. Its prosthetic group is the heme molecule; four of these are firmly attached to globin protein. The cytochrome enzymes of respiration also are conjugated proteins with heme prosthetic groups.

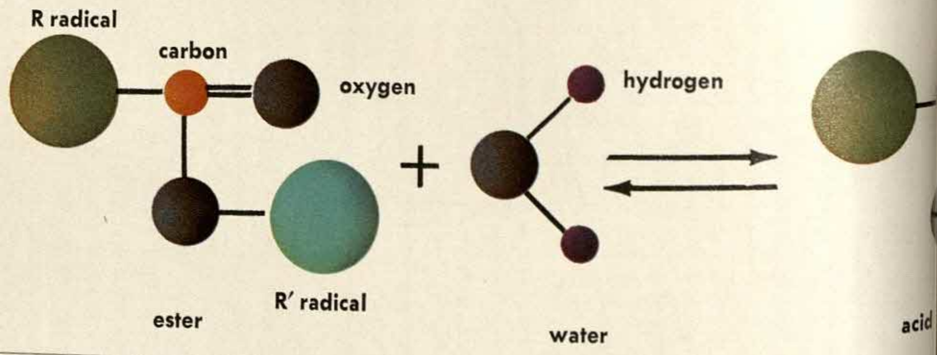
Some enzymes are synthesized in incomplete forms called zymogens. Pepsin is a protein-digesting enzyme of the stomach, but it is manufactured as the inactive pepsinogen in the gastric glands. When it is secreted into the stomach, contact with the hydrochloric acid present there removes a portion of the pepsinogen molecule and converts it into the active pepsin. Similarly, trypsinogen, chymotrypsinogen, and procarboxypeptidase are inactive forms of protein-digesting enzymes. They are formed in the pancreas and are secreted into the small intestine. Trypsinogen is converted to trypsin by the enzyme enterokinase, which is secreted by the intestine. Chymotrypsinogen and procarboxypeptidase are converted by trypsin to their active forms, chymotrypsin and carboxypeptidase. The synthesis of inactive forms of enzymes may be a mechanism that prevents the digestion of enzyme-producing cells by their own products.

One of the outstanding characteristics of enzymes is their high degree of specificity. A given enzyme catalyzes only one reaction or a group of similar reactions. The main reactant in the process is called the substrate. Many enzymes are named for the substrates on which they act. The ending of many enzyme names is *-ase*. Sucrase catalyzes the digestion of sucrose, maltase acts on maltose, and amylase acts on starch (*amylum* is the Latin word for starch). Lipase catalyzes the digestion of several lipids (fats and fatlike substances). Several proteinases act on proteins.

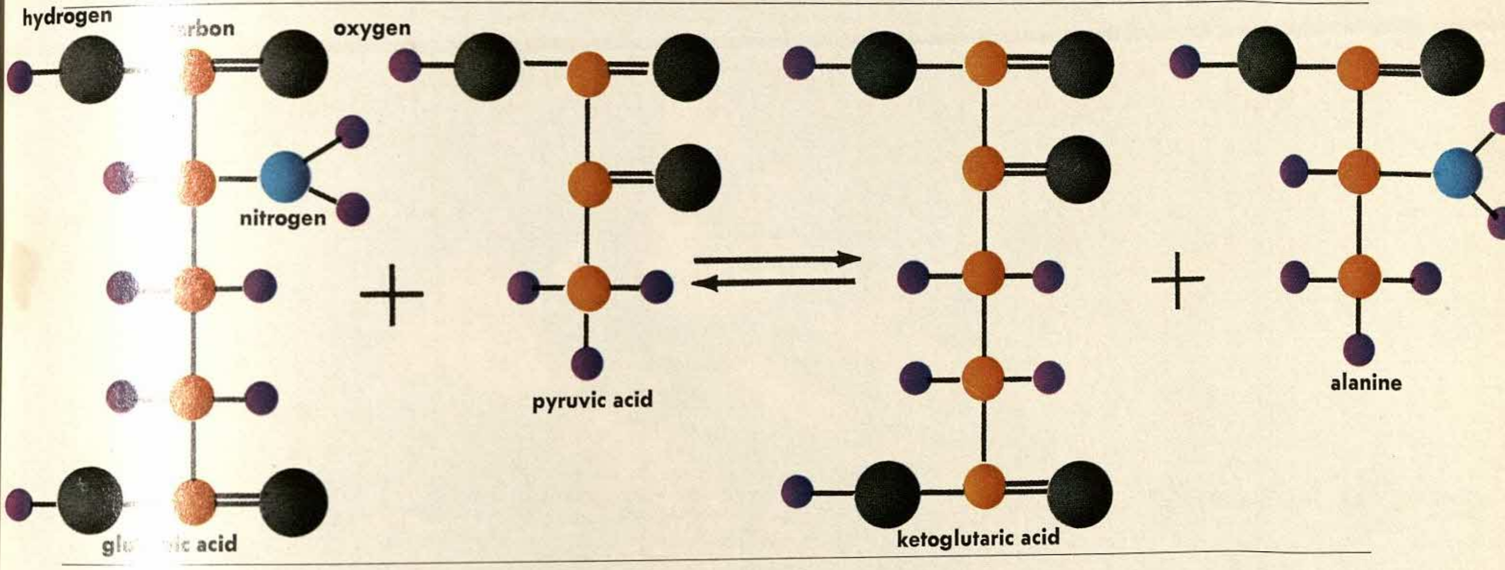
Another characteristic of enzymes is that they are not consumed by the reactions in which they take part. A given enzyme molecule can function again and again without losing any of its activity. For this reason, only very small quantities of any enzyme need be present in a cell. This explains why some vitamins, which are essential in the diet, need be present in only very small amounts, for they function as parts of coenzymes.

HOW ENZYMES FUNCTION

Chemical reactions can be divided into two groups: those that require an input of energy (endergonic reactions) and those that release energy (exergonic reactions). The former will not occur unless the required amount of energy is available. Those of the latter group may occur spontaneously, but many of these require some energy, called energy of activation, to initiate the reaction. For



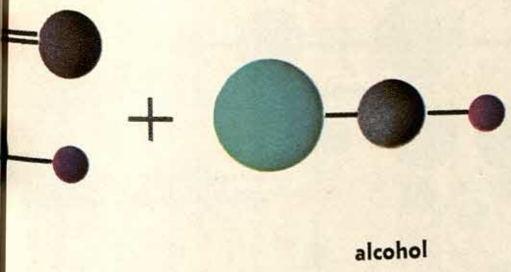
HYDROLYTIC REACTIONS—A reaction in which a compound reacts with a molecule of water and splits into two new molecules is said to be hydrolytic. The enzymes that catalyze this type of reaction are known as hydrolases. The most interesting are those involved in the digestive processes; their function is digesting or hydrolyzing polysaccharides, fats, and proteins to simpler compounds that can be absorbed by the body.



TRANSFER REACTIONS—A reaction that transfers part of a molecule to another molecule is a transfer reaction. Enzymes promoting these reactions are called transferases.

example, a burning match head releases energy, but the match does not burn spontaneously; it requires the input of a little energy, such as the heat generated by rubbing it on another surface. The chemical reactions that occur spontaneously are those that have very low activation energy requirements likely to be supplied by the warmth of the environment.

Many of the chemical reactions occurring in living things, even the exergonic reactions, have relatively high activation energy requirements that cannot be satisfied by ordinary environmental temperatures. The function of enzymes is the lowering of the amount of energy required for activation; they permit reactions to occur rapidly at ordinary temperatures that do not harm cells. The absence of enzymes in the nonliving world explains why the complex chemical reactions characteristic of organisms do not occur outside of cells.

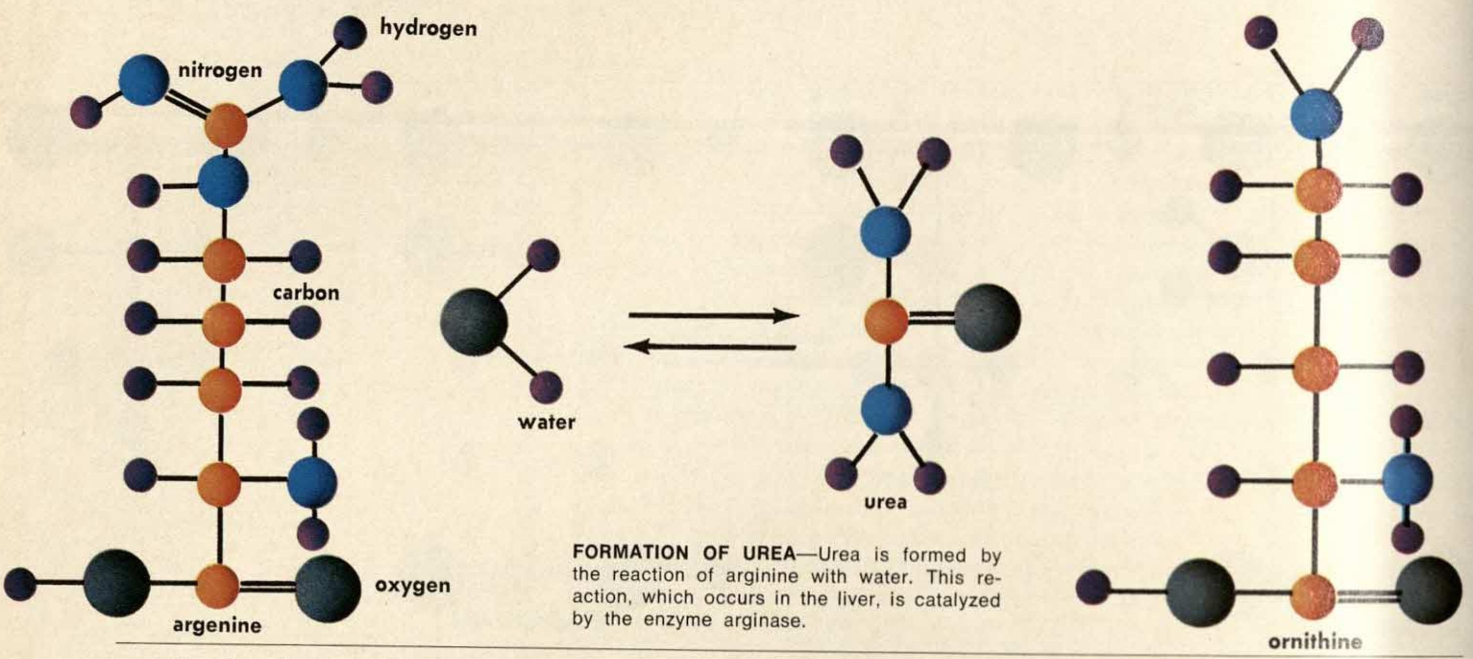


OXIDATION-REDUCTION REACTIONS

Even in the presence of enzymes, endergonic reactions require a supply of energy. For the most part, this energy is obtained from an exergonic reaction. One exception to this is photosynthesis, an endergonic reaction that utilizes light energy from the sun. This energy is converted into chemical bond energy in food molecules. Light is the main energy source for the entire biological world, even though only plants can utilize it directly. When the food is oxidized in respiration, either by plants or by animals that eat the plants, the energy is released and can be utilized in other endergonic reactions, such as growth or tissue repair and maintenance.

Much of the transfer of energy in cells occurs by means of oxidation-reduction reactions. Oxidation is a term that originally was used by chemists to describe the combination of an element with oxygen. When iron rusts, it becomes covered by a layer of iron oxide, the product of a chemical reaction between iron and the oxygen of the air. The iron is said to be oxidized. When wood is burned, the organic compounds in the wood combine with oxygen, releasing carbon dioxide and water; here, too, the wood is said to be oxidized by the burning. Gradually chemists began to realize that these examples are only specific cases of a more general phenomenon in which oxygen does not necessarily play a part. Oxidation today is defined as the loss of electrons; this occurs in both the rusting of iron and the burning of wood. In the former case, the bivalent iron (written as Fe^{2+}) loses an electron and becomes trivalent (Fe^{3+}).

Reduction is the gaining of electrons, and it occurs whenever an oxidation oc-



FORMATION OF UREA—Urea is formed by the reaction of arginine with water. This reaction, which occurs in the liver, is catalyzed by the enzyme arginase.

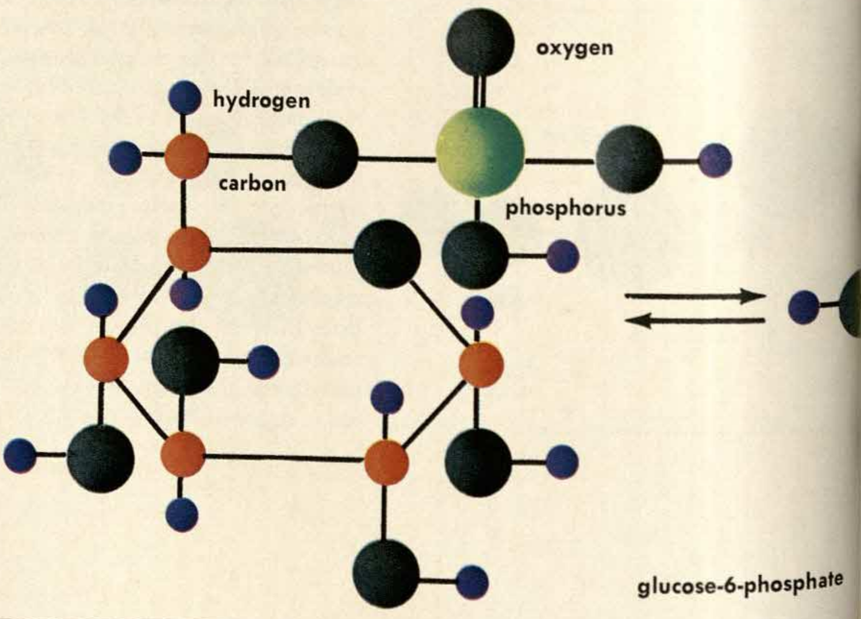
curs, for the electron released by one substance is accepted by another. In the case of rusting iron, the oxygen accepts the electron and becomes reduced as the iron is oxidized. Therefore, no reaction is solely an oxidation or a reduction. All such reactions are called oxidation-reductions. It is convenient, however, to speak of an oxidation when one is concerned primarily with the substance that is oxidized in the reaction, or to speak of a reduction when one is concerned primarily with the substance that is reduced.

The oxidation of foods in living cells is not a single reaction, but a series of reactions, almost every one of which is catalyzed by a separate enzyme. Some of these are located in the cytoplasmic matrix of cells, and others are found in the mitochondria. Within the mitochondria are the cytochromes—the enzymes that transfer electrons from organic compounds to oxygen.

Some enzymes, those that catalyze basic reactions that are performed by nearly all cells, are widely distributed in the biological world. Others are found in only certain species. The diverse and myriad forms that life takes reflect the large number of enzymes in existence.

ENZYMES AND GENETICS

One of the great achievements of molecular biology has been the determination of the structure of enzymes and the interpretation of their catalytic activity in precise atomic terms. The transformation of genetics from an abstract to a molecular science began in the 1940s. In 1865 Gregor Mendel, the father of genetics, discovered that specific genetic factors control such characteristics as height and color in plants. It was not known how the genetic factors exercise this control, however, until George W. Beadle and Edward L. Tatum, U.S. scientists, found in 1941 that one genetic factor, or gene, apparently determines one enzyme. Other important lines of research into hereditary factors pointed the way for analyzing genetic events at the molecular

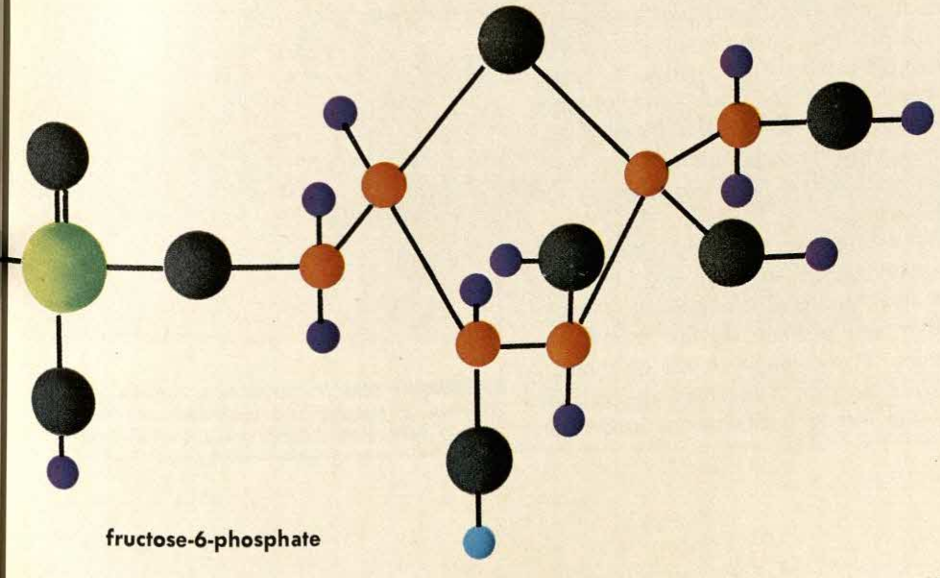


ISOMERIZATION—Reactions in which a molecule is transformed into another by modification or internal alteration are known as transformation reactions. The enzymes involved are called isomerases.

level, including the discovery of the genetic code.

Although the importance of ribonucleic acid (RNA) was realized around 1940, its functions have been understood only recently. This breakthrough came when the intricate system of RNA and protein that constitutes the chemical machinery for the biosynthesis of enzymes was isolated in the test tube. That success led to the deciphering of the genetic code itself, an accomplishment that opened up new paths of research in biology and medicine and profoundly affected medical practice. Investigations in pharmacogenetics, for example, are building a fund of knowledge. This field deals with the effect that genetic traits, which control enzyme function, have on the action of drugs in the human body.

OXIDATION—Burning wood is a typical example of oxidation. Another oxidation is the respiration that occurs in living cells. In both cases organic material is oxidized to carbon dioxide and water.



fructose-6-phosphate

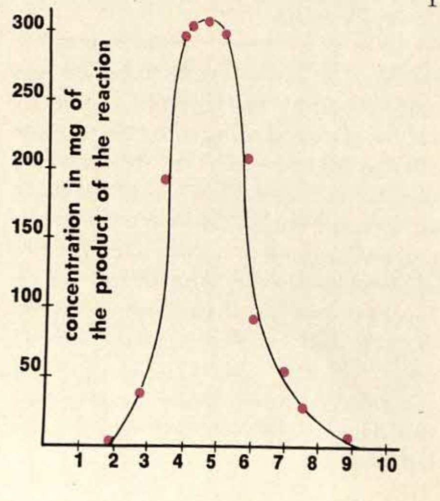
THE KINETICS OF ENZYMES

Growth, reproduction, and other vital processes in living organisms are accompanied and conditioned by a wide variety of biochemical reactions. Almost all of these reactions are influenced by enzymes—substances that regulate the rate of chemical reactions, often causing them to occur millions of times faster than they otherwise would. Without enzymes, biochemical reactions occur too slowly to support life.

Although they may also contain a nonprotein portion, all enzymes are proteins. Most enzymes are highly specific in function; that is, they catalyze only one type of reaction and/or they act on only one substrate (reactant). The protein portion (apoenzyme) of some enzymes determines the specificity for a particular substrate, while the nonprotein portion (coenzyme) determines the particular type of reaction that occurs. In some cases the specificity of the enzyme is so marked that a small change in the arrangement of a few atoms in the substrate molecule makes it impossible for the enzyme to act on it.

pH AND ENZYMATIC ACTIVITY—Many enzymes function best at an optimum pH that generally lies between 5 and 8. The graph shows a typical relationship between pH values (on the abscissa) and the activity of an enzyme (on the ordinate), expressed as the concentration of the product.

1



FACTORS INFLUENCING ENZYME ACTIVITY

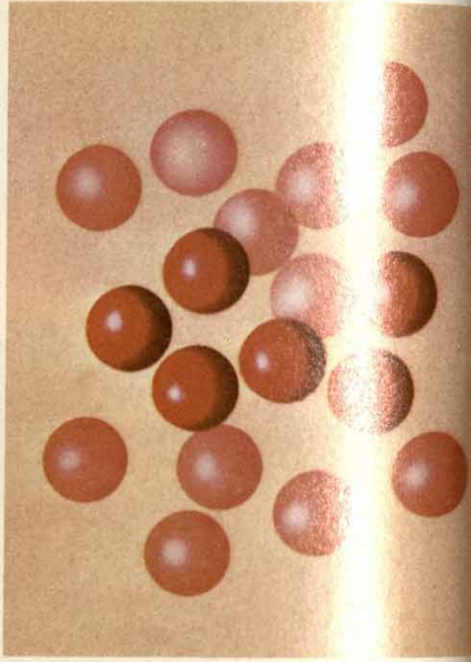
Since enzymes function by participating directly in biochemical reactions, a great deal of research has been conducted to determine what factors favor or inhibit enzyme activity. Among these factors are temperature, pH, metallic ions, chemical compounds, pressure, and radiation. Although these factors may influence each other, they are considered separately here.

Enzymes are very sensitive to temperature. For each enzyme there exists a minimum and a maximum temperature below and above which it does not function. Somewhere between these limits, there is an optimum temperature at which the enzyme functions best; for many enzymes the optimum temperature lies between 30° and 35° C (86° and 95° F). The maximum temperature usually is only a few degrees above the optimum temperature, but in a few cases it may be as high as 70° or 80° C (158° and 176° F). At their maximum temperatures, enzymes begin to undergo chemical or physical changes that inactivate them—often permanently. Low temperatures generally do not damage enzymes, but their activity is slowed, especially at temperatures below 0° C (32° F). Upon warming, activity is regained.

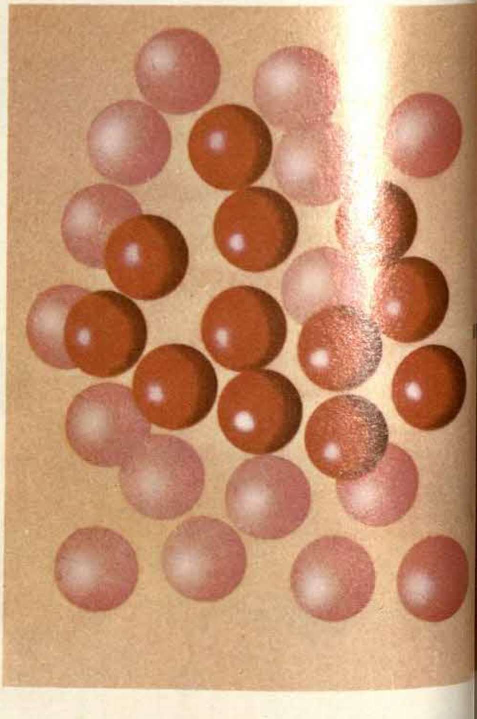
Most enzymes are extremely sensitive to changes in the pH of the solutions in which they act. Each kind of enzyme has its minimum, optimum, and maximum pH. For most enzymes, the optimum pH lies between 5 and 8. However, a few enzymes have a more acid or more alkaline optimum pH; the digestive enzymes of the stomach, for example, function well in the acid contents of the stomach.

A number of heavy metals—such as mercury, silver, and zinc—are poisonous because they inhibit enzymatic activity. Ether and acetone do not inhibit enzymes. Many nonpoisonous compounds block the action of enzymes; among these are the products of enzymatically con-

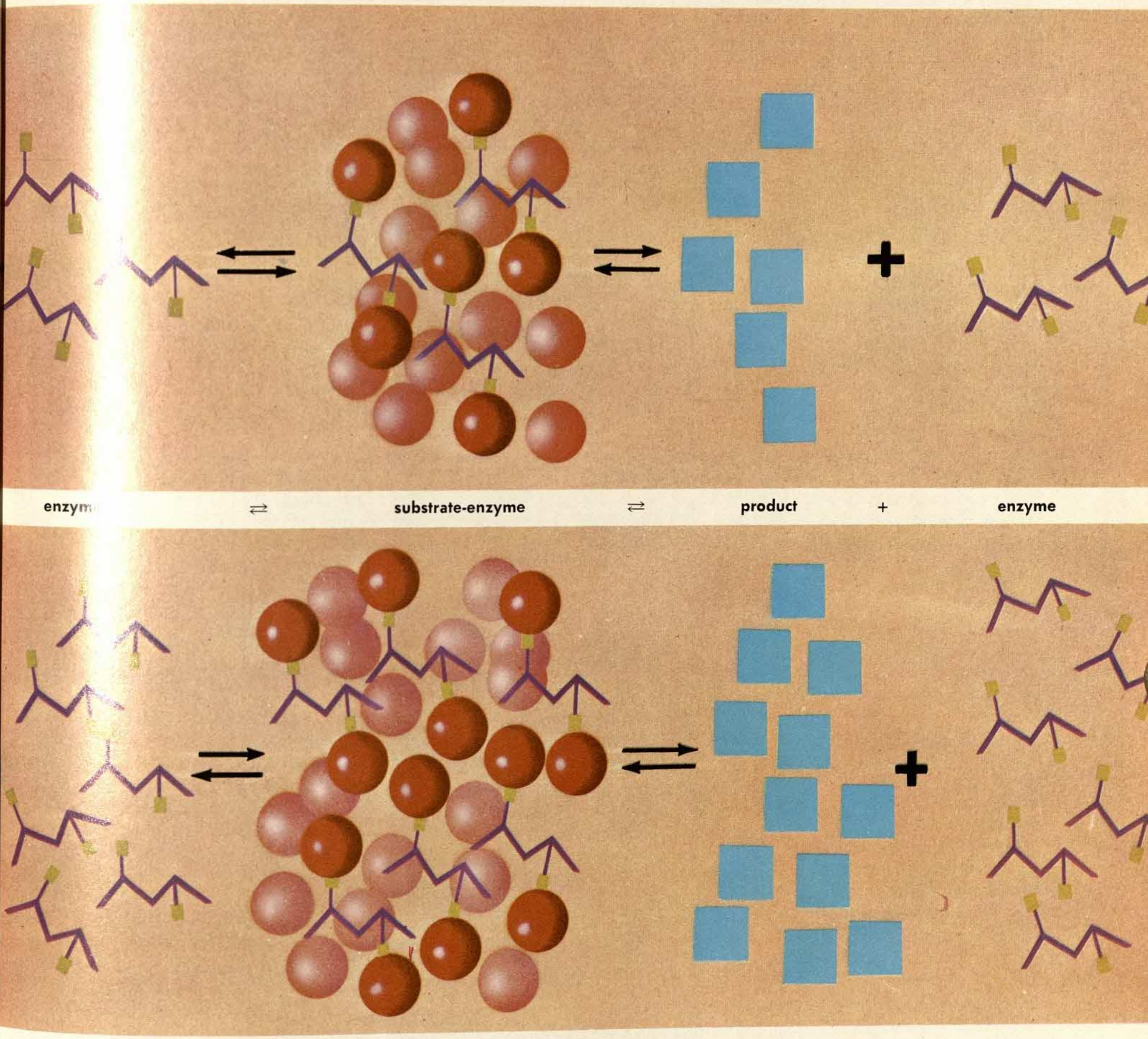
2a



2b



ENZYMATIC REACTION—Illustrations 2a and 2b show a schematized enzymatic reaction. In 2b an increase in the quantity of the en-



zyme causes it to react with more substrate molecules, thus increasing the rate of reaction because the number of the molecules of the substrate involved in the reaction increases. The red balls represent the substrate, the purple figures represent the enzymes, and the blue squares represent the new product. The two-directional arrows indicate that the reaction can proceed in either direction.

trolled reactions. If the product of a reaction accumulates in the cell, the reaction slows down and may even stop. The reaction will continue, however, if the product is removed to another cell or organ or if it is used up in another chemical reaction.

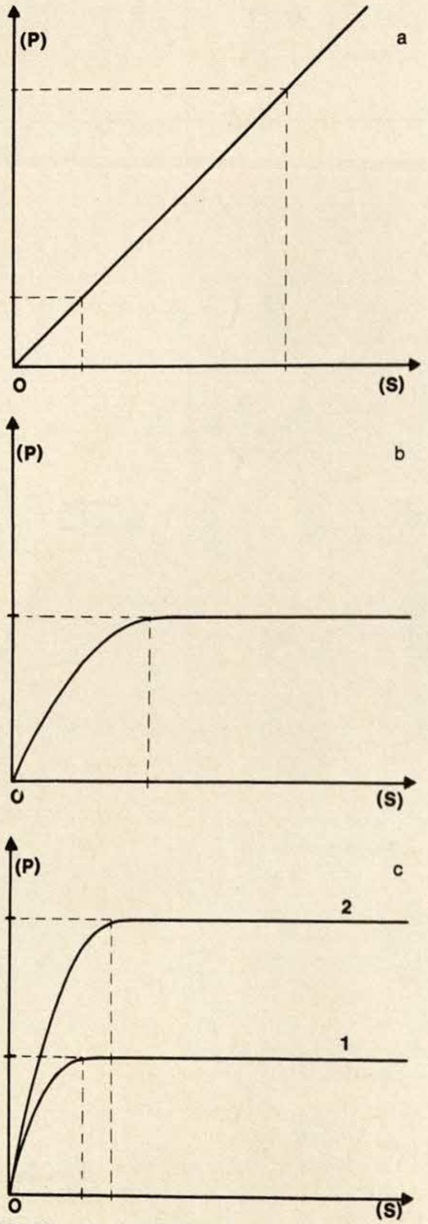
Very high levels of mechanical pressure inactivate enzymes, but complete inactivation may require a pressure as high as 17,000 atmospheres (about 250,000 psi). Since enzymes are not ordinarily subjected to such pressures, pressure is a negligible factor.

Radiations may inhibit or activate enzymes. X-rays, beta rays, and gamma rays have a damaging effect on enzymes, but alpha rays are activators.

THE NATURE OF ENZYMATIC REACTIONS

The molecules of all substances are in constant motion, and they collide with one another repeatedly. For a chemical reaction to occur between two molecules, these molecules must collide at a certain speed. It is necessary, therefore, that they possess a certain amount of kinetic energy (energy of motion). Some of this energy is called *energy of activation.* The more energy of activation required for a particular reaction, the faster the molecules must be moving. Molecules can be speeded up by being heated, although in living organisms too much heat may cause tissue damage and even death. One of the most important characteristics of enzymes is their ability to lower the amount of energy of activation for many essential chemical reactions in living things. Since less heat is required, the reactions can occur at temperatures compatible with life.

Illustration 2a shows what occurs in an enzymatic reaction: $S + E \rightleftarrows SE \rightleftarrows P + E$. Here S stands for the substrate, E for the enzyme, and P for the product of the reaction. When S and E react, they form an intermediate compound, SE, the substrate-enzyme complex. S then undergoes a chemical change converting it to P, and E is released. In this way enzymes lower the amount of energy needed for a reaction because the energy of activation required for either $S + E \rightarrow SE$, or $SE \rightarrow P + E$ is much less than that required for converting S to P without the help of enzymes.



SPEED OF REACTION—The three graphs compare the curve of a nonenzymatic chemical reaction **a** with those of an enzymatic reaction **b** and **c.** The concentration of the substrate **S** is indicated on the abscissa, and the speed of reaction in terms of concentration of product **P** is indicated on the ordinate. In a nonenzymatic chemical reaction the curve is a straight line—indicating that the speed of the reaction is directly proportional to the concentration of substrate. In the enzymatic reaction **b**, if the concentration of the enzyme remains unchanged, the speed of reaction is proportional to **S** only up to the point at which the enzyme becomes saturated; after that the rate remains constant. In **c** curves 1 and 2 are similar to the curve in **b**, but in curve 2, the enzyme concentration is double that of curve 1; once the enzymes are saturated with substrate, the rate of the reaction is proportional to the concentration of the enzyme.

Although the enzyme is involved in the reaction, it emerges unchanged and can be used again and again. Although enzymes need be present in cells in only minute amounts, they exert a great effect on the life of the cell.

The arrows in the illustration point in opposite directions to indicate that the reaction is theoretically reversible. Usually, a point of equilibrium is reached wherein some substrate molecules and some product molecules exist side by side. How much of each remains in a cell depends on such factors as the particular reaction, the temperature, the pH, and whether the product is removed or is permitted to accumulate. In many cases the point of equilibrium is shifted so far to one side of the reaction that, for all practical purposes, the reaction seems to go in only one direction.

THE RATE OF AN ENZYMATIC REACTION

In a common chemical reaction that is not controlled by enzymes, the rate of the reaction may depend on the concentration of the only reactant (this is a first-order reaction) or it may depend on the product of the concentrations of two reactants (this is a second-order reaction). In an enzymatic reaction, however, the speed of reaction ordinarily does not depend on the concentration of reactants, and this is therefore known as a zero-order reaction.

Since the enzyme is usually present in very low concentration as compared to that of the substrate, at any one moment all of the enzyme molecules are involved in substrate-enzyme complexes (the enzyme is said to be saturated); however, not all of the substrate molecules are so involved. Therefore, the rate of an enzymatic reaction depends largely on the concentration of the enzyme rather than on the concentration of the reactants. Thus, doubling the concentration of the enzyme usually doubles the speed of the reaction because this also doubles the number of substrate molecules involved in the reaction. Only when the number of substrate molecules is so low that not all of the enzyme molecules are saturated will the rate of the reaction be affected by the substrate concentration.

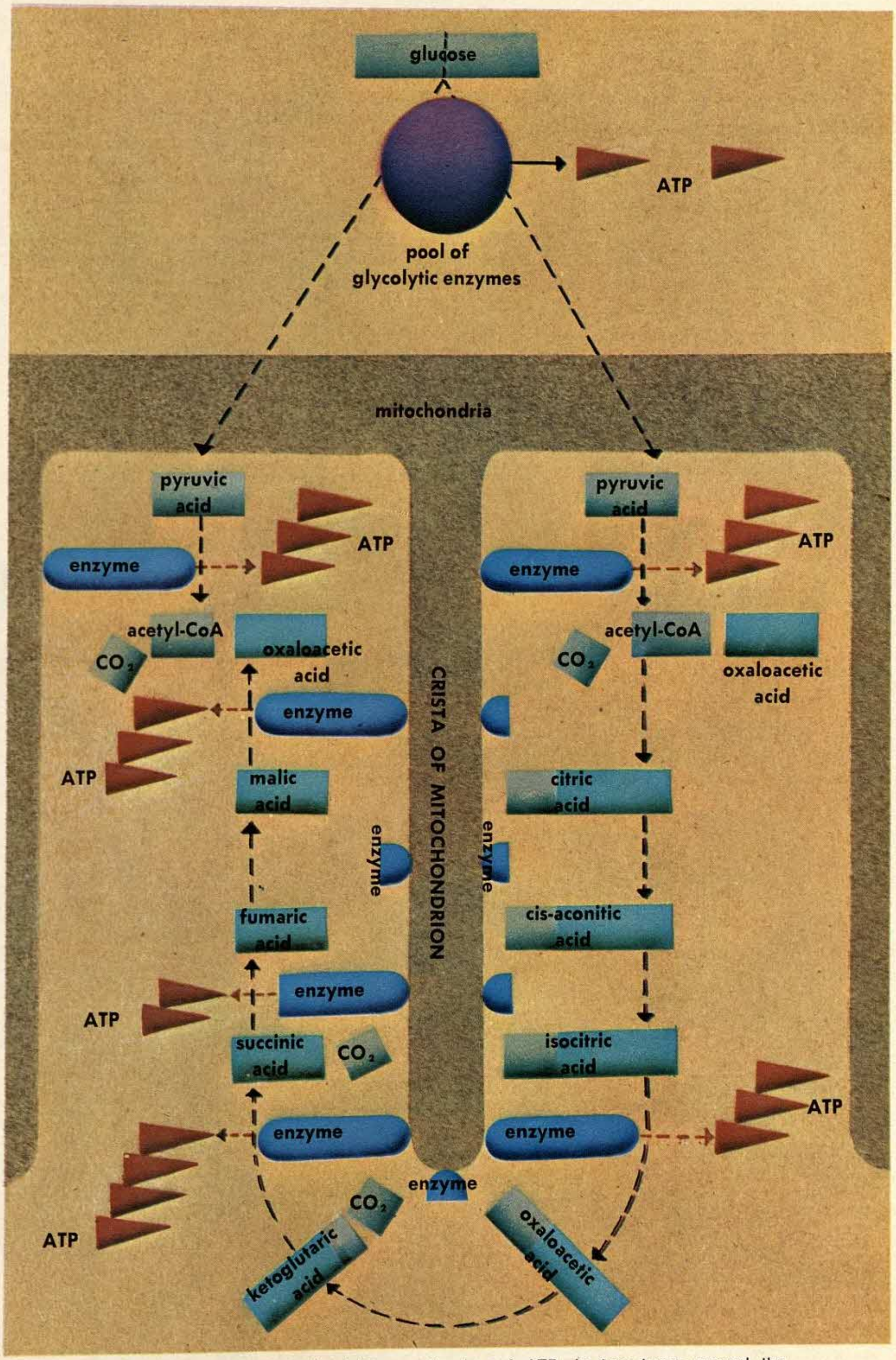
STOREHOUSES OF ENERGY | calories imprisoned in molecules

The three functions of food are to build protoplasm, the basic substance of all living things; to provide the energy needed for all the activities of life; and to regulate the complex chemical reactions that go on in living organisms. Eating gives strength in proportion to the number of calories the food contains. A calorie (cal) is defined as the amount of heat required to raise one gram of water one degree Centigrade. The large calorie (Cal), used when speaking of food requirements, is one thousand times as much as the small calorie. The number of calories is a convenient way of evaluating the energy of food, since heat is a form of energy. The more readily a food is digested, the more immediately available is the energy that it contains.

The three basic food types are carbohydrates, fats, and proteins. While these differ from one another in a number of ways, they share one common trait—all are composed of long chains of carbon atoms linked with one another. Energy is released as the bonds between the atoms of these strongly linked, stable compounds are broken. Although these bonds do not break easily in air, they break quickly inside a cell because of the presence of a large number of cellular enzymes. Enzymes are protein catalysts that facilitate chemical reactions in a living system. The chemical breakdown of food within cells is an oxidation process, and like oxidation outside of cells, the products are carbon dioxide, water, and energy. Unlike oxidation outside of cells, however, cellular oxidation (also called cellular respiration) takes place by means of many small steps, so that the carbon and hydrogen removed during oxidation of the food compound are not immediately and simultaneously combined with oxygen. This avoids the sudden release of a large amount of heat, which might damage the cells and disallow the storage of energy for future use. Cellular respiration is, therefore, a controlled combustion in which energy is released slowly, with a relatively small increase in temperature.

CELLULAR RESPIRATION

Many of the important steps in cellular respiration take place inside the mitochondria, which are minute, variously



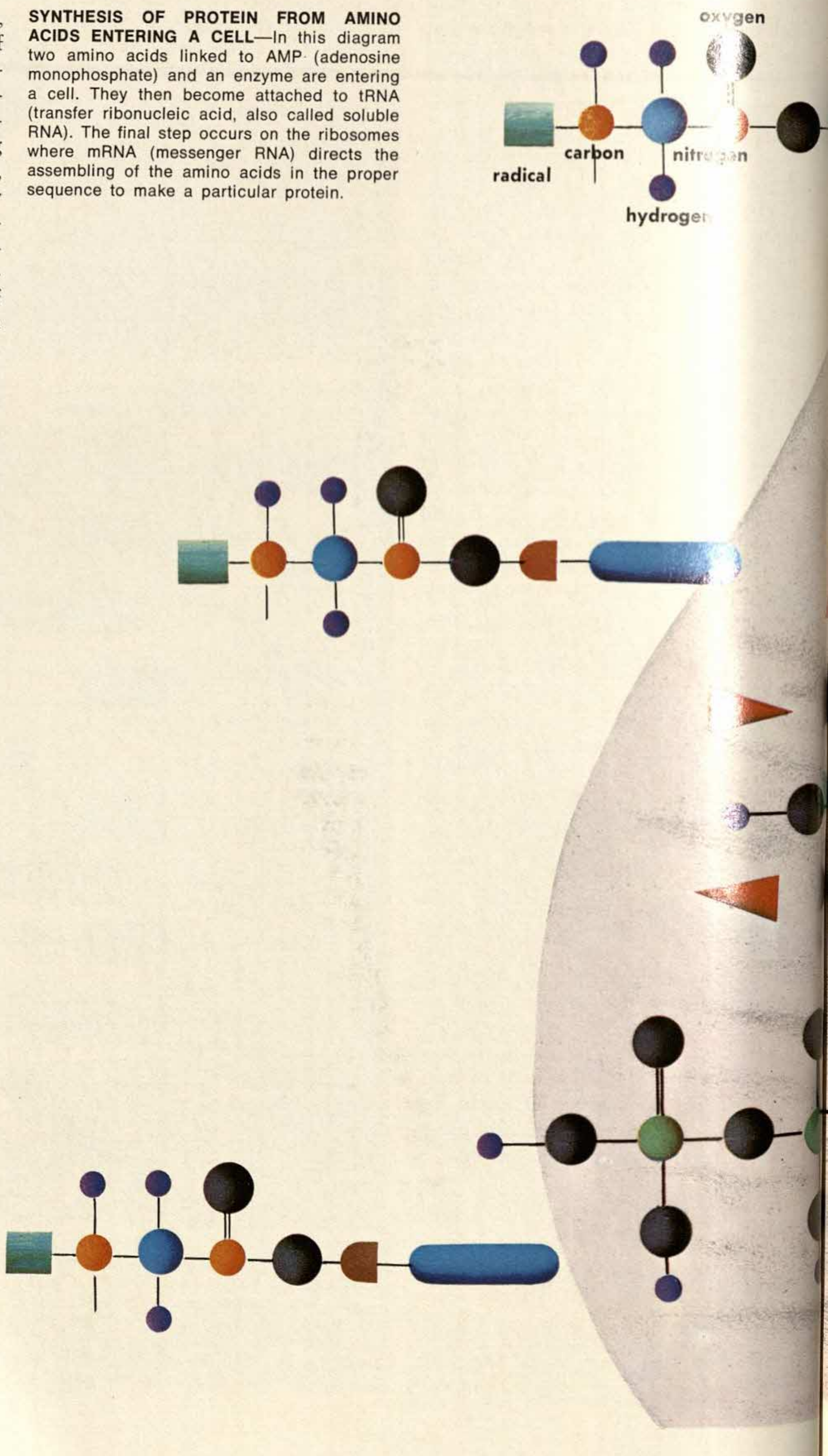
KREBS CYCLE—This important cycle (also called the citric acid cycle) is the third step in cellular oxidation (respiration). It takes place along the membranes (cristae) inside the mitochondria. Glycolysis yields two molecules of ATP. The conversion of the two pyruvic acid molecules from the oxidation of glucose to two acetyl-CoA molecules yields six molecules of ATP. In two turns around the Krebs cycle, glucose is finally broken into carbon dioxide and hydrogen. The hydrogens, after a number of transfers, unite with oxygen to form water. In this last step, 24 ATP molecules are harvested, yielding a total of 32 ATPs from one molecule of glucose.

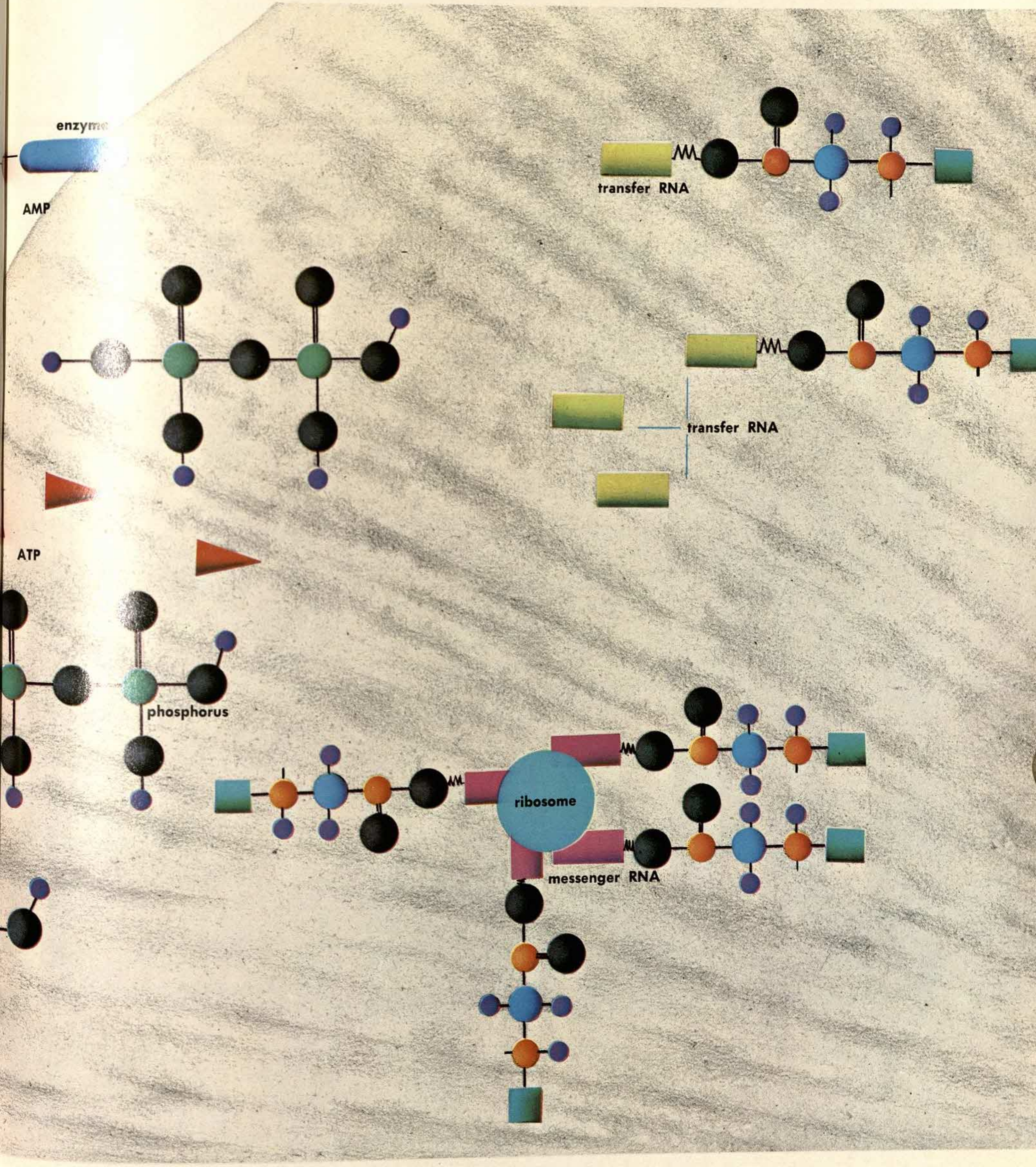
shaped cell organs (organelles). Cristae, made of the folded inner membrane of the mitochondria, project into the mitochondria and provide an extensive surface on which are located a large number of enzymes in orderly series. Using the oxidation of glucose, a simple sugar, as an example, cellular respiration may be divided into four main steps: (1) glycolysis, which breaks the 6-carbon glucose molecule into two molecules of 3-carbon pyruvic acid; (2) conversion of pyruvic acid (derived from both glucose and amino acids) to a 2-carbon derivative of acetic acid called acetyl-coenzyme A; (3) metabolism of two 2-carbon acetyl-CoA molecules (derived from pyruvate and from fatty acids) by means of the citric acid or Krebs cycle into four carbon dioxide molecules and eight hydrogen molecules; and (4) transfer of accumulated hydrogen molecules by way of a long chain of carriers until they unite with oxygen, thus forming water. Each of the four steps requires a number of enzymes. During the last step, most of the energy from the broken bonds of the food materials is stored in the form of adenosine triphosphate (ATP). Each molecule of ATP contains two high-energy phosphate bonds. At the end of the oxidation of one glucose molecule, energy has been packaged in 32 ATP molecules, each one of which can release small quantities of energy as needed for cellular work.

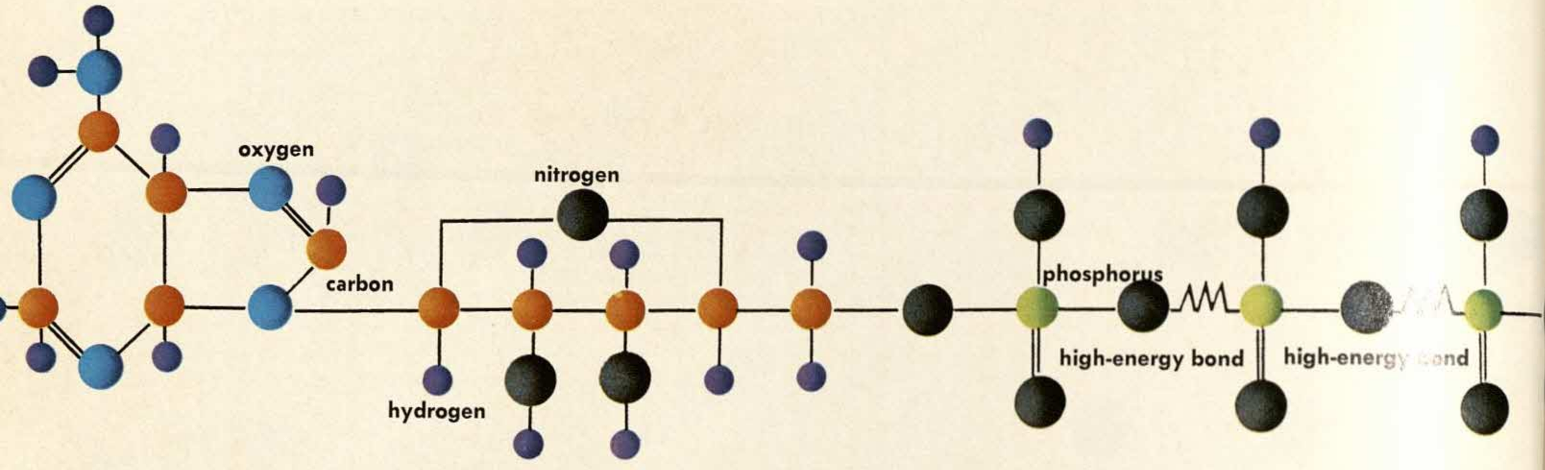
FUNCTION OF ATP

The energy released during cellular respiration and stored in ATP may be used in two ways: it may be kept bound in ATP and thus stored for future use; or it may be used immediately for cellular work. Such work includes providing energy for the respiratory steps themselves, for muscular contraction, for the conduction of nerve impulses, for the construction of the many compounds that compose protoplasm, and for the production

SYNTHESIS OF PROTEIN FROM AMINO ACIDS ENTERING A CELL—In this diagram two amino acids linked to AMP (adenosine monophosphate) and an enzyme are entering a cell. They then become attached to tRNA (transfer ribonucleic acid, also called soluble RNA). The final step occurs on the ribosomes where mRNA (messenger RNA) directs the assembling of the amino acids in the proper sequence to make a particular protein.




enzyme
AMP
transfer RNA
transfer RNA
ATP
phosphorus
ribosome
messenger RNA



THE ATP MOLECULE—This important energy-storing compound is made up of a nitrogen base (a ring compound called adenosine), a 5-carbon sugar, and three phosphate groups. The high-energy bonds between phosphorus and oxygen are shown with zigzag lines. ATP releases energy for all bodily activities when the high-energy bonds are broken.

of light in bioluminescent animals such as fireflies, and in some fungi and bacteria. In any case, when energy is required, one of the high-energy phosphate bonds is broken and ATP becomes ADP (adenosine diphosphate). Removal of one phosphate radical breaks one of the two high-energy bonds and releases energy for whatever job needs to be done.

PROTEIN SYNTHESIS

Since some of the most important chemical components of living organisms are protein (for example, enzymes and parts of chromosomes, cell membranes, and cytoplasm), the ability to synthesize protein is an essential characteristic of life. Proteins are made of hundreds or thousands of amino acids bonded together in various ways to make single enormous molecules. Animals eat the proteins of plants or other animals and digest them, thus breaking them into amino acids. After entering the cells these amino acids are reassembled to make the specific proteins that the animal needs at a particular moment. In order to bring about such complex syntheses, energy from ATP, enzymes, a set of "blueprints" derived from the chromosomes, and a "factory" (the ribosomes)—must all be available in the proper sequence. The entire process may be considered under four headings:

1. Absorption of amino acids by the cells
2. Amino acid activation
3. Transfer of amino acids to ribosomes
4. Linkage of the properly lined-up amino acids into proteins by the formation of peptide bonds (a dehydration synthesis)

Absorption of amino acids.—The process by which amino acids enter a cell consumes energy, since the concentration of amino acids inside the cell is usually greater than the concentration outside. Passive diffusion, therefore, does not account for the passage of amino acids, nor for the speed of that passage, from a region of less amino acid concentration to one of greater concentration. While the details of such passage against a gradient have been worked out for glucose, they are not yet known for amino acids; it is probable, however, that energy from the reaction ATP → ADP is involved.

Activation of amino acids.—Once inside the cell, the amino acid becomes activated. This occurs when an enzyme specific for that amino acid and a molecule of ATP react with it. In the process two phosphate groups are given off. The enzyme makes possible the attachment of the amino acid to a molecule of tRNA (transfer ribonucleic acid, also known as sRNA, soluble ribonucleic acid). This can be summarized as follows:

amino acid + an enzyme + ATP →
aminoacyl-enzyme-AMP (adenosine
monophosphate) + 2 phosphate
groups (a pyrophosphate).

In a second reaction the enzyme and the AMP become detached as tRNA attaches to the amino acid.

Transfer of the amino acid to the ribosomes.—Ribosomes are very small organelles scattered throughout the cytoplasm. They are made of rRNA (ribosomal ribonucleic acid). Another type of RNA is called mRNA (messenger RNA). It is made in the nucleus and its component parts are assembled in a specific order by a portion of the DNA (deoxyribonucleic acid) of a chromosome acting as a template. mRNA is a chainlike filament that becomes draped over the ribosomes or possibly looped around them. A tRNA exists for each of the 20 possible amino acids. When a particular kind of protein is to be manufactured, the tRNA carries the right assortment of amino acids to particular places on the mRNA filament.

Linkage of the amino acids.—The amino acids, still attached to their tRNAs, are brought close to one another in the correct order to make a particular protein by the code (blueprint or directions) built into the mRNA. Enzymes then facilitate the union of the amino acids by means of peptide linkages. The peptide linkage is a dehydration synthesis, meaning that a molecule of water is lost for each pair of amino acids that become linked. Such dehydration reactions are common in the synthesis of carbohydrates and fats as well as in the synthesis of proteins. Once the protein is synthesized, it separates from tRNA and mRNA.

MICROSCOPY AND HISTOLOGICAL TECHNIQUE

preparing tissue for observation

Until the microscope was invented and adequate methods of preparing plant and animal material for microscopic observation have been devised, scientists could not study the finer structures of living things. Not until the middle of the nineteenth century—the time when good microscopes were first made—did scientists discover that cells are the building blocks of all living organisms. Since that time more and more information about cells has been discovered as higher-powered, higher-precision microscopes have been built, and as more revealing methods of preparing tissues have been devised.

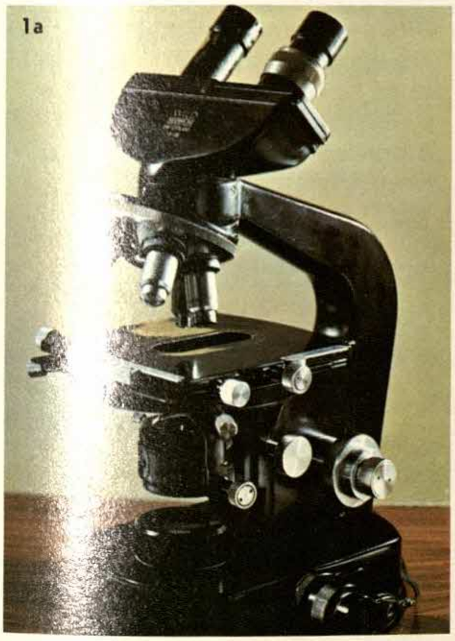
The science of using a microscope is called microscopy. The preparation of plant and animal tissue for microscopic observation is called histological technique. High-quality microscopes and well-prepared plant and animal tissue are necessary if one is to learn about the minute details of living organisms.

Modern compound optical microscopes are of excellent quality, both mechanically and optically. The mechanical part is called the stand; it is the framework of the microscope and consists of a base, a stage with an opening in its center over which the prepared specimen is placed, a tube into which the ocular lens (eyepiece) fits, an arm by which the microscope is carried, and a revolving nosepiece into which a number of threaded objective lenses are screwed. The tube is fitted with a rack-and-pinion device that permits raising and lowering the tube over the stage. The rack-and-pinion is controlled by two pairs of knurled knobs. One pair, the coarse adjustment mechanism, allows the tube to be moved rapidly through several inches. The other pair of knobs, which controls the fine adjustment mechanism, raises or lowers the tube by much smaller increments and is used in the final focusing.

The optical parts of the microscope consist of a substage condenser and light system, the oculars (eyepieces), and the objective lenses. A microscope may be either monocular or binocular; that is, it may have either one ocular or two. While a monocular microscope is adequate for most routine work, a binocular microscope is advantageous for more prolonged or detailed study since most people find that it is less tiring to use both eyes; also, two oculars produce a slightly stereoscopic or three-dimensional view of the object.

Most microscopes are equipped with low and high-power objectives, but research instruments may have four or more objectives for a wider range of

THE OPTICAL MICROSCOPE—A binocular microscope (Illustration 1a) consists of a stand, shown separately in Illustration 1b. Various lenses and a substage condenser can be attached to the stand as desired. Illustration 1c shows objectives of several powers of magnification. Illustration 1d shows objectives mounted on the revolving nosepiece, which makes possible a quick change of magnification. The view is from below. Illustration 1e shows two oculars (eyepieces). Illustrations 1f and 1g are photomicrographs of diatom shells (325 X and 160 X). Their finely marked lines are used to test the resolving power of a microscope.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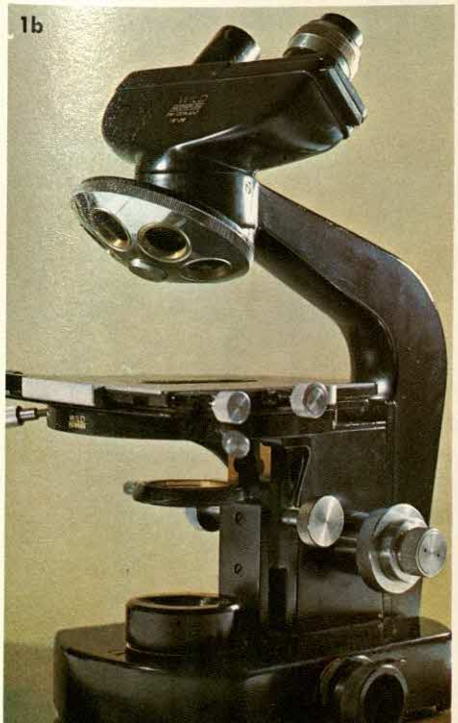
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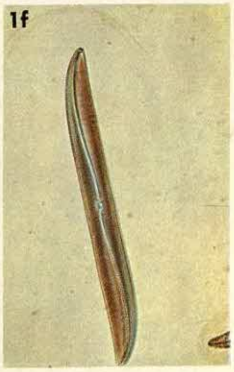
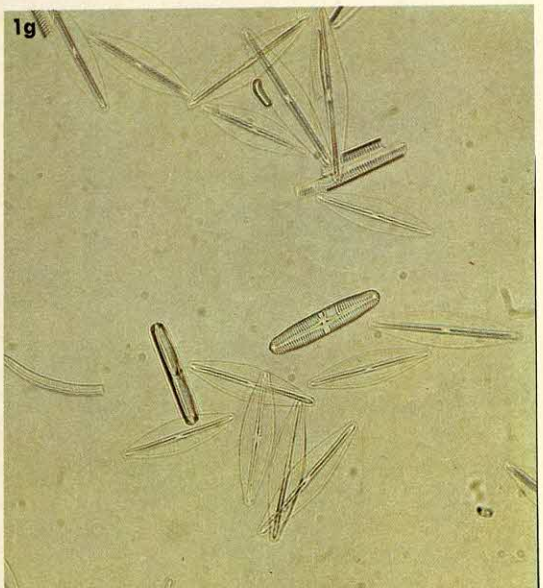

1f


1g

magnification. An objective, which is a series of lenses cemented together, forms an inverted image, which is in turn magnified by the lenses in the ocular. The higher the power of the lens, the shorter its focal length, so that with very high power the lowest lens of the objective is extremely close to the slide. A good objective has several important characteristics: it must have good resolving power, and it must be free of both spherical and color aberration. Resolving power is the ability of a lens to distinguish details that are very close together. It is achieved by a lens that is as wide as possible for the amount of magnification that it can have. Freedom from spherical aberration means that a lens focuses as sharply at its periphery as it does at its center. If no iridescent color bands are present at the periphery of the field of vision, the lens is free of color aberration; in other words, the lens is achromatic.

Some high-power objectives are described as "dry," meaning that only air is present between the lens and the cover glass. Other high-power objectives are described as "oil-immersion," meaning that oil is placed on top of the cover glass so that the front lens of the objective is immersed in it. For the highest magnification and the clearest image, oil-immersion lenses are almost always used. This is because without oil the rays of light coming from the illuminated specimen undergo considerable bending as they pass through the slide and cover glass into the air and again as they pass into the glass of the lens. This bending is due to the different indices of refraction of the materials through which the light passes. If a suitable oil (cedarwood or crown oil) with the same refractive index as glass is placed on top of the cover glass and the lens is immersed in the oil, no deviation of the light rays occurs and the image is sharper.

Several light systems are now in use. A commonly used system consists of a light source, preferably one producing a bluish light, a mirror, a series of substage lenses (the condenser), which focus the light on the object, and an iris diaphragm, which can be opened or closed by a shutterlike system of leaves.

HOW THE MICROSCOPE IS USED

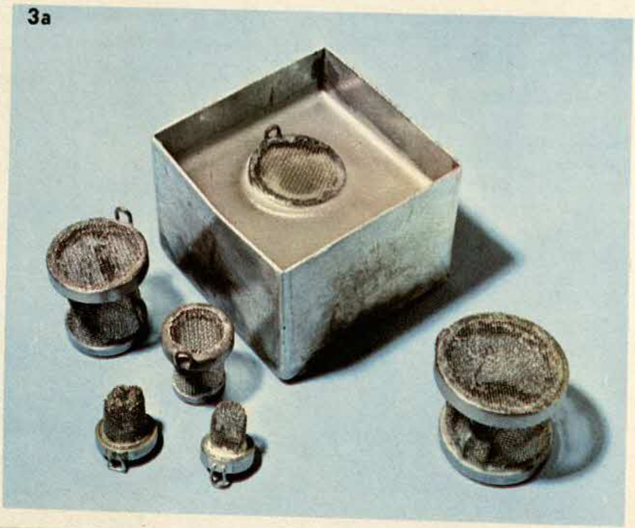
All lenses must be clean to assure a clear, sharp image. Since lens glass is easily scratched, only the softest paper should be used in cleaning the lenses; specially prepared lens paper is recommended. The microscope slide is placed on the stage with the specimen to be examined over the opening. While looking through the microscope with the low-power objective in place, the light is adjusted by turning the mirror until the light is sharply concentrated on the specimen. The intensity of the light is changed by opening or closing the iris diaphragm.

The focusing procedure is always started with the low-power objective in place; since the field of vision of the low-power objective is larger than that of a high-power objective, more of the object will be in sight and a selection of a suitable area for more detailed examination can be made. In addition, there is less dan-

FIXATION AND DEHYDRATION—Fixation, an important first step in the preparation of tissue for microscopic examination, serves to kill the tissue rapidly and to preserve its structure practically unaltered. Illustration 2a shows a piece of tissue in a fixative consisting of 95 percent alcohol, glacial acetic acid, formalin, and sodium chloride. The tissue must be embedded in paraffin before it can be thinly sectioned. Since paraffin is not soluble in water or alcohol, the specimen must be gradually dehydrated by immersing it in a succession of alcohol baths of increasing concentration, followed by a final immersion in xylene or toluene (Illustration 2b), aromatic hydrocarbons used as solvents.

2a

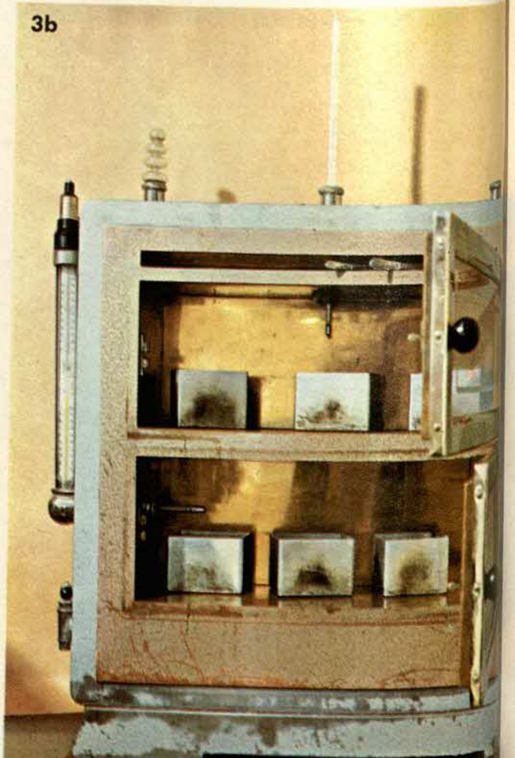
3a

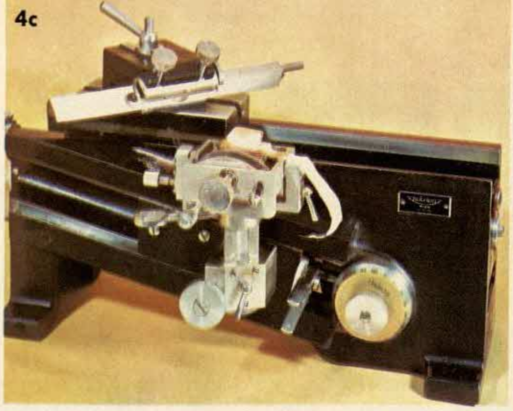


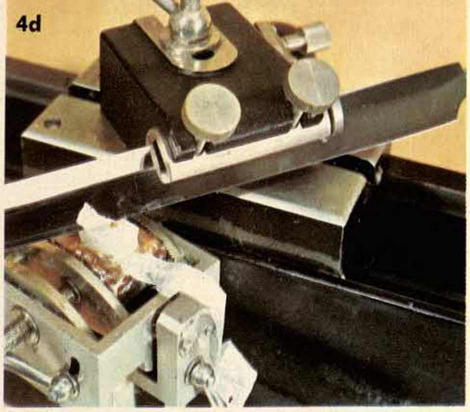
2b

EMBEDDING IN PARAFFIN—After the xylene bath, which may last from 15 to 20 minutes or more according to the size of the piece of tissue, the piece is ready to be embedded in paraffin. Illustration 3a shows one type of container in which the tissue is placed when it is immersed in melted paraffin. Illustration 3b shows an oven containing paraffin of different melting points. The use of paraffins having various melting points is determined by the tissue and by outside conditions. Small blocks of paraffin eventually form and solidify around the specimen.

3b







FROM PARAFFIN BLOCKS TO SECTIONS—Illustration 4a shows a large block of paraffin containing several pieces of tissue. The various strips of paper serve as labels to identify individual specimens. The large block is cut into smaller blocks, each with one piece of tissue attached. These smaller blocks are trimmed and mounted on wood or metal disks by melting the paraffin slightly on its underside and pressing the block onto the object disk. Illustration 4b shows the block, ready for sectioning, attached to the object disks. Illustration 4c shows a sliding microtome, an apparatus equipped with a very sharp blade that cuts extremely thin slices. Illustration 4d is a close-up view of the microtome. Routine sections are cut 5 to 10 microns thick; for special study, sections may be cut as thin as 2 or 3 microns. With a rotary microtome, the paraffin block moves against the knife.

ger of breaking the cover glass, since the focal length of the low-power lens is long enough so that there is little danger of its touching the cover glass. To focus, the low-power objective is lowered with the coarse adjustment knob until it is about ½ in. from the slide. Then, as the observer looks through the ocular, the lens is raised. Final focusing is done with the fine adjustment knobs.

In order to examine the specimen under high power two methods can be used. If the microscope is parfocal (meaning that if an object is in focus under low power it will also be in focus under high power without much additional focusing), the high-power objective is swung into place and final focusing adjustments are made with the fine adjustment knob. If the microscope is not parfocal, it is safer to raise the tube slightly before swinging the high-power lens into place. Then, as the observer looks through the ocular, the tube is moved downward with the fine adjustment knob until the object is in focus. When an oil-immersion lens is used, it is best to focus first with high power, after which the high dry lens is swung out of the way, a drop of the immersion oil is placed on the cover glass, and the oil-immersion lens is brought into place. The front lens of the objective will be in the oil and hence both lens and the slide must be cleaned carefully after use. The higher the power of the objective, the more intense the light must be, so mirror and iris diaphragm need to be adjusted each time the objective is changed. When transparent, unstained specimens are being examined, the light intensity must be diminished either by changing the position of the mirror or by changing the size of the opening in the iris diaphragm.

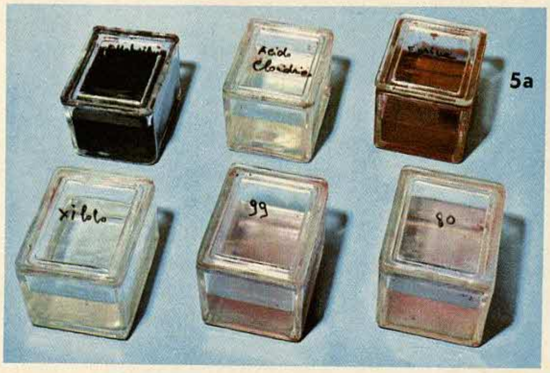
Objectives can be tested for spherical aberration by using a microscope slide that has a very fine grid of perpendicular lines. If, when examined under the microscope, the grid squares are not distorted in any way in any part of the field of vision, the lenses are free of spherical aberration. To test for resolving power, a microscope slide of shells of diatoms is used. These shells, which consist of siliceous compounds, are marked with extremely fine lines that lie very close to each other. A good microscope will show the lines separately and distinctly. Some laboratories have a series of specially prepared slides of such shells on which these patterns become progressively finer. It is customary to watch for color aberration while looking at these test slides.

Different powers of magnification can be achieved by different combinations of oculars and objectives. The magnifying powers of each are engraved on these lenses; total magnification power is calculated by multiplying the power of the objective by the power of the ocular. While increasing the amount of magnification is often helpful in examining a specimen, it is not usually necessary to exceed a magnification of about 1,000 times—the magnification achieved with the usual combination of oculars and oil-immersion lenses. Unless the slide is unusually well prepared, increasing the magnification will not make the details any clearer; in fact, it may magnify some faults in slide preparation. A good plan is to use a medium-power ocular (one that magnifies 10 times) with either a high dry (43 X) or oil-immersion (98 X) objective. This will give a total magnification of 430 X or 980 X. Microscopes employing a variable power, or zoom, lens between the objective and the eyepiece were introduced in 1960.

EXAMINATION OF FRESH MATERIAL

When fresh, unpreserved plant or animal parts, tissues, or cells are examined under the microscope, they must be placed in a solution that preserves their natural, living condition as closely as possible. In order to accomplish this in the case of animal tissues, solutions from an animal of the same or closely related species may be used to keep the tissue moist and in its natural condition. Fluids that can be used include aqueous humor from the eye, amniotic fluid from the sac around a developing embryo, and blood serum. The difficulty of having such fluids available at short notice is obvious; hence, in actual practice this method is rarely used. Instead, artificial solutions that approximate the chemical characteristics of animal fluids are used. Such solutions are known as physiological solutions and have proved quite satisfactory. That most frequently used is made with sodium chloride at a concentration determined by whether the tissue is from a cold-blooded animal such as a fish, frog, or turtle, or from a warm-blooded animal such as a bird or mammal. For use with frog tissue, about a 0.7 percent salt solution is satisfactory; for use with mammal tissue a 0.9 percent salt solution is satisfactory. A good all-purpose solution for mammals is made up of 0.9g NaCl, 0.04g KCl, 0.02g $NaHCO_3$, 0.02g anhydrous $CaCl_2$, and 100 ml distilled H_2O. The solution should be prepared immediately prior to use since evaporation of any of the water changes the strength of the salt solution.

A small piece of tissue is then placed on a microscope slide and a drop of physiological salt solution is added. The tissue is gently pulled apart with dissect-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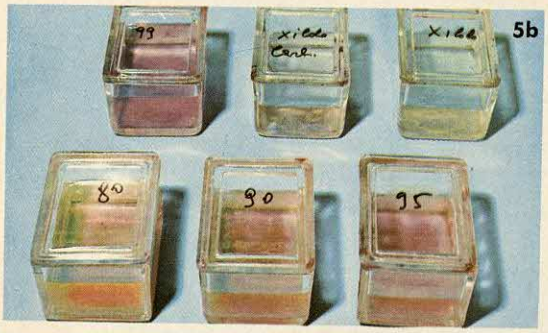
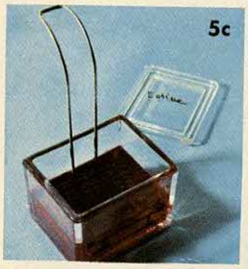

5b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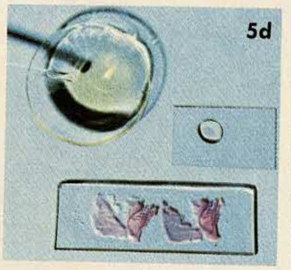
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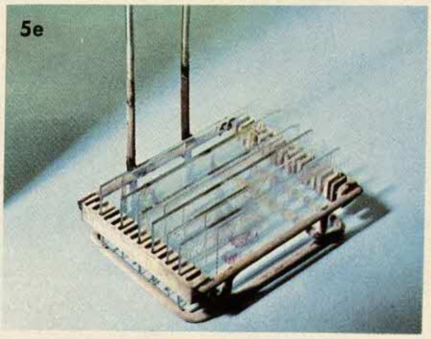
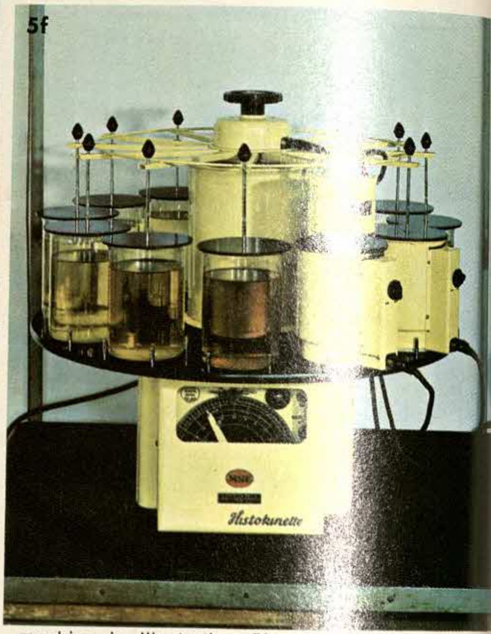

5e


5f

STAINING—After sectioning, the slices of tissue, still embedded in paraffin, are attached to glass microscope slides with a thin layer of glycerinated egg albumen. The tissue is now ready for staining. As the dyes used for staining are generally soluble in water, it is first necessary to remove the paraffin and then to hydrate the specimens by placing them successively in baths of xylene and alcohol, a process just the reverse of that applied when the tissues were dehydrated before being placed in paraffin. Illustrations 5a, 5b, and 5c show the jars used in this hydration operation. Illustration 5d shows the stained sections ready for mounting in balsam. A cover glass with a small drop of balsam on it is shown above the slide. Illustration 5e shows finished slides, in a carrier, ready for observation. The machine in Illustration 5f automatically performs the operations just described.

ing needles so that it is thin and so that the fibers are dissociated enough for the cells, muscle, or nerve fibers to be observed under the microscope. The difficulty with this method is that it is almost impossible to separate the individual cells so that several layers are not superimposed, thereby making it difficult to see individual cells clearly. Another difficulty is that unstained living tissue is almost colorless, so that details of cellular structure cannot be seen unless the microscope has a phase contrast objective.

MAKING A PERMANENT SECTION

While theoretically it is better to observe tissue that is still in its natural living condition, a clear understanding of tissue structure is almost impossible to achieve in this way. Several other methods have been devised. If the tissue is very thin or has been pulled apart carefully, it may be stained and preserved without sectioning. After staining, a cover glass is placed on the slide. This does not, however, solve the problem of making the tissue thin enough to see individual cells clearly. Therefore, almost all slides used in the study of both plant and animal tissue are of sectioned tissue. The process includes a number of steps: Fixation is the rapid killing and preservation of the tissue. A good fixative must not shrink or otherwise distort the tissue and it must preserve the tissue. Many fixing solutions contain formalin because tissues stain well after fixing in formalin, which is neutral and which does not harden tissues excessively. The important thing is that fixation should be carried out as soon as the tissue is dissected from the animal or it should be preserved in 70 percent alcohol or 5-10 percent formalin. The next important step is embedding the tissue in paraffin so that it can be cut more easily. Since neither alcohol, water, nor formalin will mix with paraffin, however, it is necessary to find a solution that mixes with both the fixative and paraffin. Xylene and toluene are the most generally used solutions. First, all the water must be removed from the fixative or preservative, a process called dehydration. This is accomplished by replacing the aqueous solution with higher and higher concentrations of alcohol. The absolute alcohol can now be replaced with xylene or toluene.

The tissue is now placed in melted paraffin at a temperature only a few degrees above the melting point of paraffin. After about an hour, the melted paraffin has infiltrated through the tissue. The tissue is now removed to a small paper, metal, or plastic box into which is poured fresh melted paraffin. The paraffin in the box is then cooled rapidly in cold water, thus embedding the tissue in a solid block of paraffin, which can be cut very thin.

The paraffin block with its contained tissue is cut or sectioned on a microtome. Either a sliding or a rotary microtome is used. The sliding microtome utilizes a large, razorlike blade that slides across the paraffin block; in the rotary microtome, the paraffin block moves up and down against the knife.

The sections, still with a thin layer of paraffin around them, are attached to glass microscope slides with a thin layer of glycerinated egg albumen. The sections are now dried on a slightly warmed plate.

To make cellular details visible and to reveal something of their chemical nature the sections must be stained, preferably with two contrasting stains, one a basic dye that brings out details of the nucleus, and the other an acidic dye that brings out details of the cytoplasm. Since dyes are soluble in either water or alcohol, the paraffin around the sections must be removed before staining begins. This is done by immersing the slides, with the attached sections, in xylene followed by several immersions in decreasing concentrations of alcohol.

The final step in the preparation of the slide is covering the section with a cover glass. Excess stain is removed and the sections are again dehydrated and placed in xylene, which is miscible with the mounting medium, Canada balsam, a natural resin. A drop of balsam is placed on the section on the slide, and the cover glass is placed on top of the balsam.

ULTRATHIN SECTIONING

histological techniques for electron microscopic observation

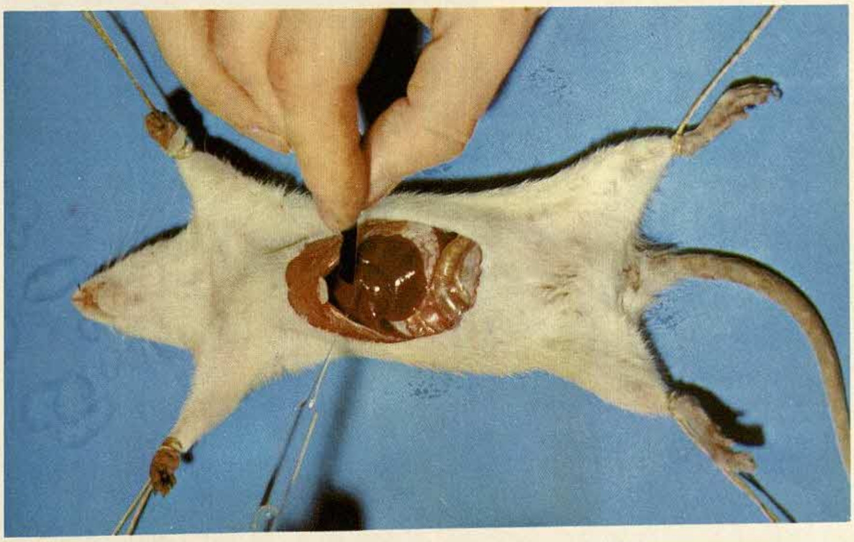
The preparation of material to be observed through the electron microscope is, in itself, an exacting procedure. If the specimen is to be observed in a clear field, that is, observed by transmitted radiation, it must be extremely thin so that the electron beam can pass through it and produce an image on a fluorescent screen or photographic film. The specimen must be strengthened and stabilized so that it can withstand heat, exposure to a vacuum that will remove water or other volatile substances from it, and bombardment by electrons.

As a general rule, the thickness of the section to be observed should be less than 1,000 Å (1 Angstrom unit equals 1/250,000,000 in. or 0.0001 μm). Using special techniques such as those described here, scientists slice animal and plant tissues to the thickness of a single cell or less, a few millionths of an inch. Some materials such as metals cannot be sliced so thin without altering their structure, and they must be observed by other methods.

In the positive image produced by the electron microscope, light areas correspond to parts of the material that present only a slight obstacle to the passage of electrons and cause only slight scattering of the electrons. Darker areas correspond to parts of the material that cause more scattering of electrons, due to some variation in molecular structure or chemical composition. Strong contrast is produced when the electrons pass through atoms of widely differing atomic weights. The light elements with low atomic numbers cause little scattering of electrons and produce a light area on the image, while heavy elements with high atomic numbers cause much scattering and produce a dark area. Biological materials contain chiefly such light elements as carbon, nitrogen, oxygen, and hydrogen, which cause little scattering. To create more contrast, and make details more clearly visible (in somewhat the same way as specimens to be studied optically are stained with colored dyes) biological materials are often impregnated with chemicals that contain heavy atoms.

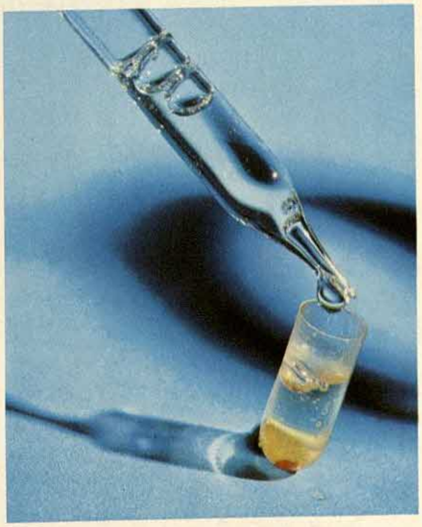
Even a good photograph produced by the electron microscope may appear quite unlike one of the same subject, enlarged to the same degree, taken with an optical microscope. For example, the nucleus of a cell looks much larger in an electron microscope photograph. Some scientists feel that the techniques of building and using the electron microscope have progressed much more rapidly than the techniques of interpreting the images they produce.

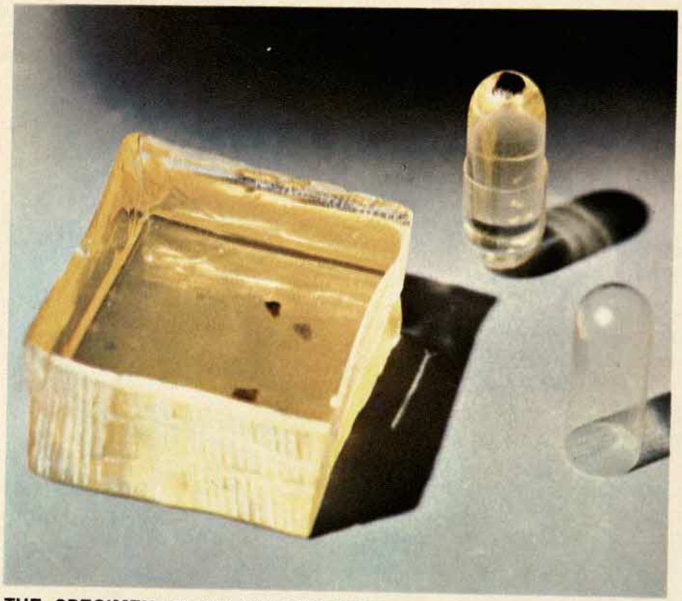
OBTAINING THE SPECIMEN—In this case, the object to be studied is tissue from a rat's liver. Only a small quantity of tissue, usually less than 1 mm^3, is required. It is removed from the animal shortly after death. Appropriate methods for preparation then follow.



DEHYDRATING AND FIXING THE TISSUE—The first step in preparing the specimen is treating the tissue to ensure its preservation. It is immersed in caustic soda, which removes water from the tissue. A small percentage of osmium tetroxide serves to stabilize the structure of the tissue and also to increase contrast by means of its heavy atom content.

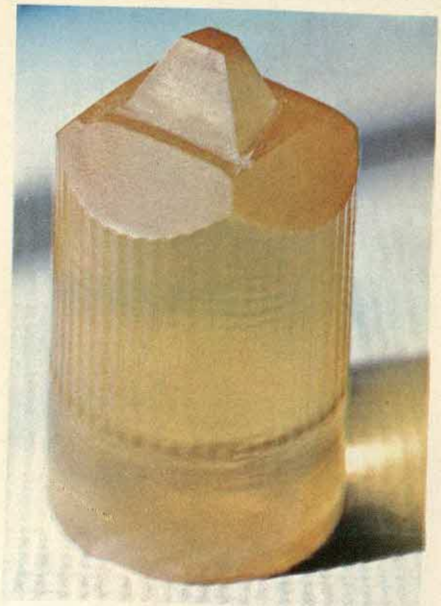
EMBEDDING THE SPECIMEN IN PLASTIC—The tissue is placed in the bottom of a small capsule-shaped glass container, and a synthetic resin, in liquid form, is poured over and around it. When the resin has impregnated the specimen and hardened, the specimen will be embedded in a clear but rigid material that can be cut with a knife.





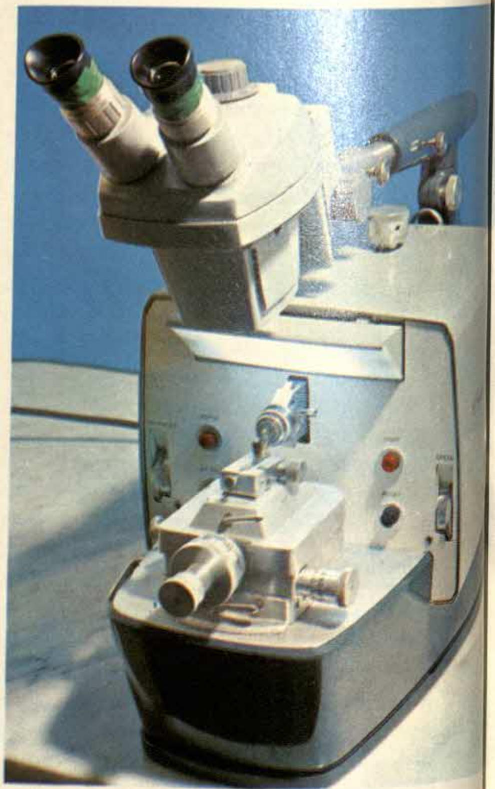
THE SPECIMEN IN ITS PLASTIC MATRIX—Once the resin has hardened, it can be removed from the glass container. This photograph shows the resin plug turned over so that the specimen is at the top. The plastic used to impregnate specimens is shown in block form. It is a monomeric resin that hardens by polymerization.

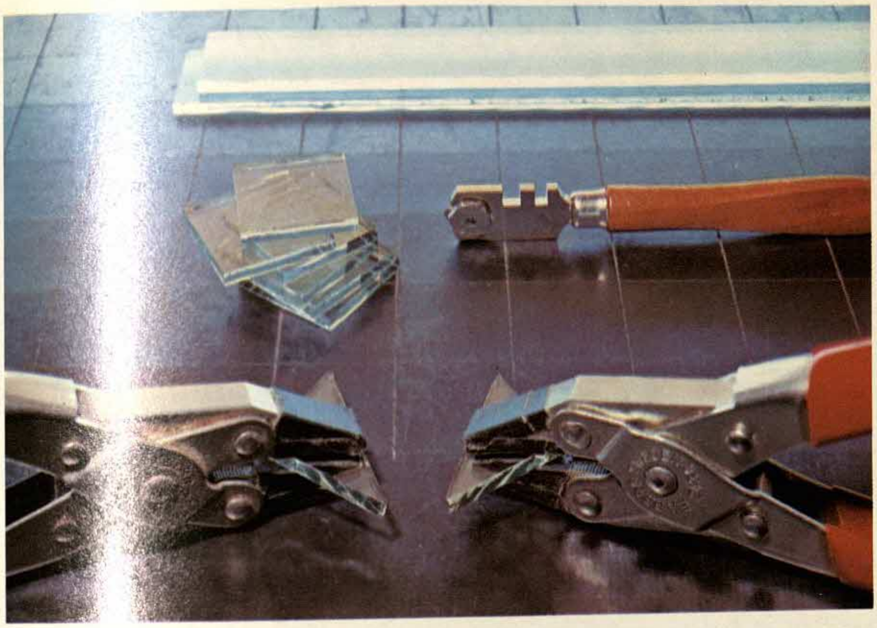
FINAL PREPARATION FOR SLICING—Still more resin, and unneeded parts of the specimen, are cut away so as to isolate the part that is to be observed. This operation is done by hand, by a skilled technician who uses a razor blade and a binocular microscope. When he is finished, the block will resemble a sharpened pencil, with the important part of the specimen at the pointed tip.



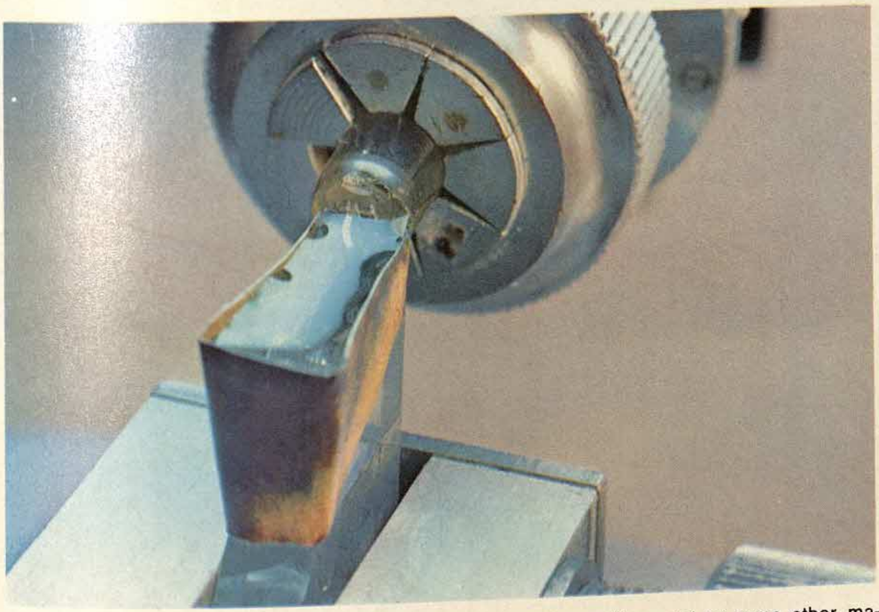
THE PYRAMID—Excess resin is cut away in a preliminary slicing operation. The part of the biological specimen that is of interest is now near the top of the pyramid, at the tapered end of the cylinder. At its widest point, the cylinder is less than 0.5 in. in diameter.

THE ULTRAMICROTOME—The actual slicing is done by a precision machine, the ultramicrotome. It is similar to microtomes used to section specimens for the optical microscope, and not too different from an ordinary slicing machine. The specimen, mounted in an adjustable chuck, extends out from the vertical face of the machine, while the cutting blade extends up from the base. When the machine is in operation, the specimen is advanced toward the blade between one cut and the next, a distance equal to the thickness of the section wanted. The binocular microscope and light at the top of the machine make it possible for the operator to observe the slicing process.

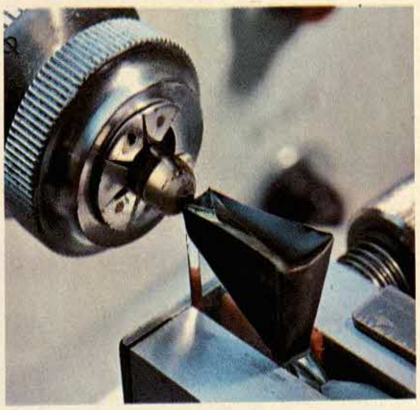




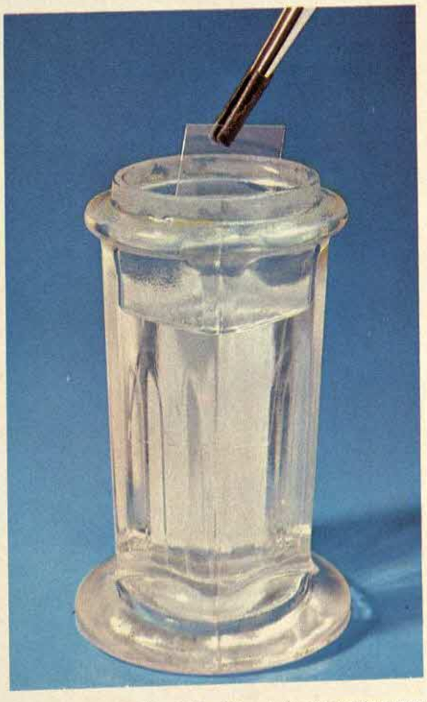
THE CUTTING BLADE—A specially cut diamond may serve as the cutting blade of an ultramicrotome, but broken glass, which is cheaper and easier to obtain, is more widely used. The technician making a new blade starts with a small square of plate glass. With a diamond-tipped glass cutter he marks a diagonal across the square. He then breaks the glass along this line by pulling the two triangles apart with two pliers. The edge created in this way is cleaner and straighter than if the glass had been broken by bending it along the line, the usual method of cutting glass. One point of the triangle becomes the cutting blade.



THE BLADE IN POSITION—This photograph and the following one show the triangular piece of glass mounted in the ultramicrotome, with the acute angle that forms the cutting blade at the top, near the chuck that holds the specimen. The structure mounted on top of the glass triangle is a trough or basin constructed of thin metal or some other material and filled with water. The ultrathin sections to be sliced off the specimen will fall into this trough and float there, supported by the surface tension of the water. Successive slices will float alongside each other, in the order in which they were cut.



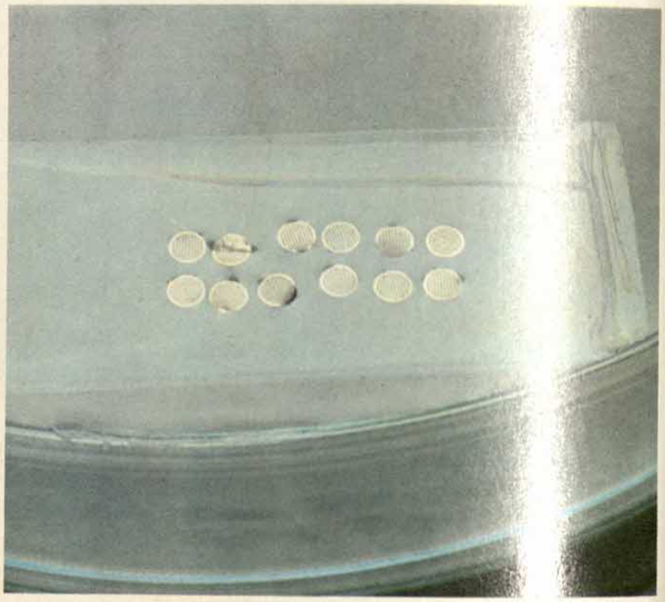
PREPARATION FOR SLICING—This photograph shows the blade, trough, and chuck from another angle. The ultramicrotome is now ready for the sectioning operation. The sections are much too fragile to be handled with even the most delicate tweezers. They will be scooped up on special holders, circles of wire mesh that have been covered with a thin, transparent membrane.

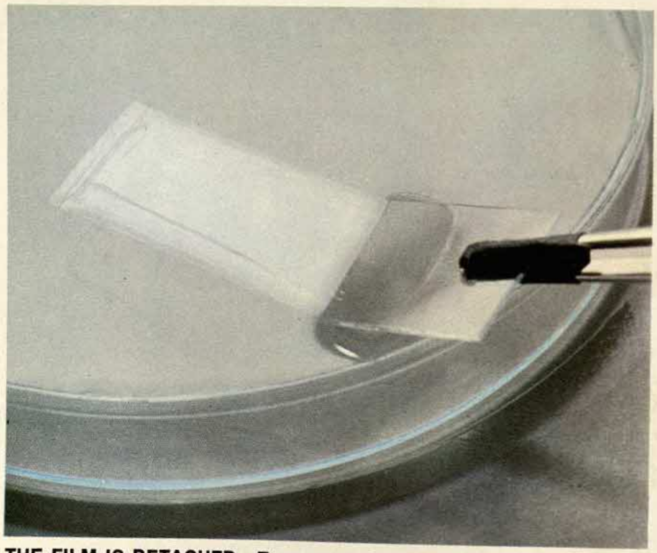


THE FILM SUPPORT—The transparent membrane that is to support the ultrathin section must be strong but very thin—usually less than 300 A in thickness. It should be composed of atoms of low atomic numbers, so that excessive scattering of electrons by the support will not obscure details of the biological material to be studied. One material widely used for this purpose is a polyvinyl formal resin. The thin film is formed by evaporation. In this picture a glass slide is being dipped into a 33 percent by weight solution of polyvinyl formal resin and dioxane, a very dilute solution. A thin coating of the solution will cling to the slide when it is lifted out. The glass slide must be extremely clean. Before it is used for this purpose, it is washed in a sulfochromic acid solution and dried in an oven.

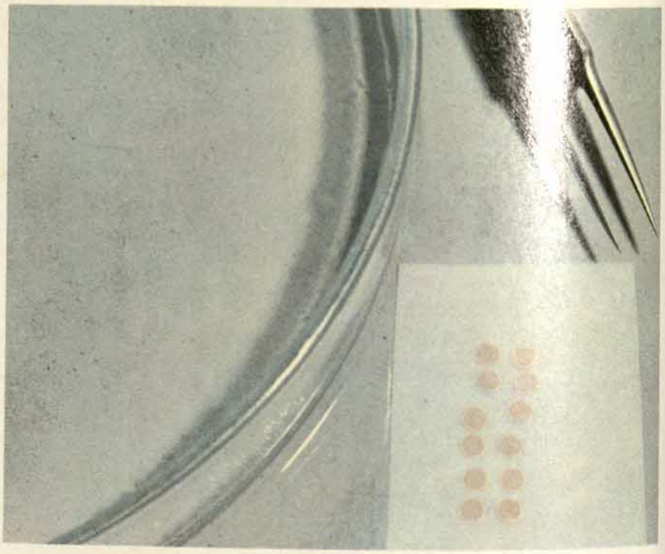
DRYING THE FILM—The slide is held over a hot plate so that the rising current of warm air dries the slide and its coating. The dioxane evaporates, leaving a very thin film of polyvinyl formal resin on the glass.

THE FILM IS ATTACHED TO THE HOLDERS—Tiny disks of wire mesh are slipped under the floating film. The disks, which are about 1/8 in. in diameter, adhere to the film. The holes in the mesh are about 0.[illegible]3 in. in diameter; there are 200 holes to the inch in the mesh material.



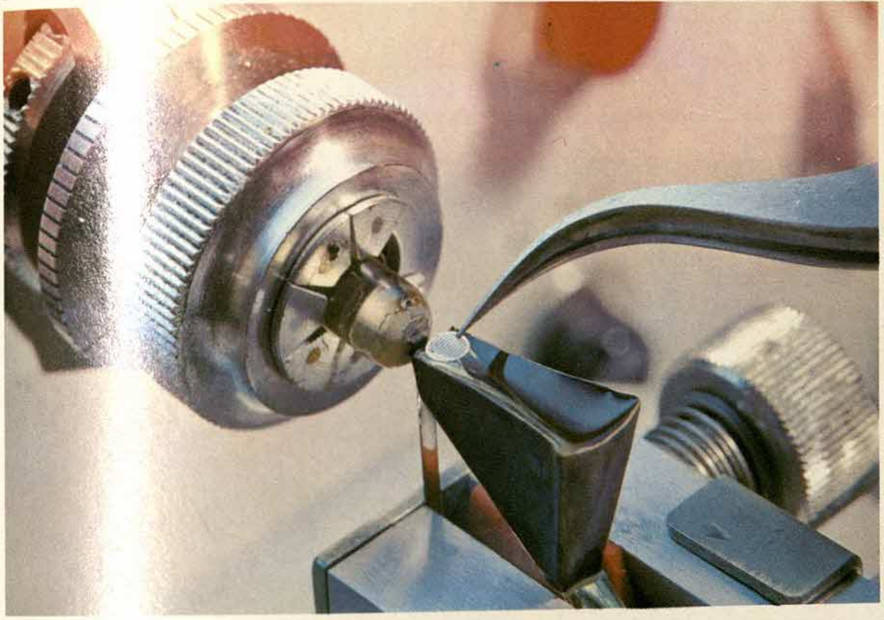


THE FILM IS DETACHED—To remove the film from the glass, the technician dips the slide into water. The film comes loose and floats to the surface. The water used in this operation is distilled water, poured into a clean container and carefully inspected. Any specks of dust that settle on the surface of the water are removed before the slide is immersed.

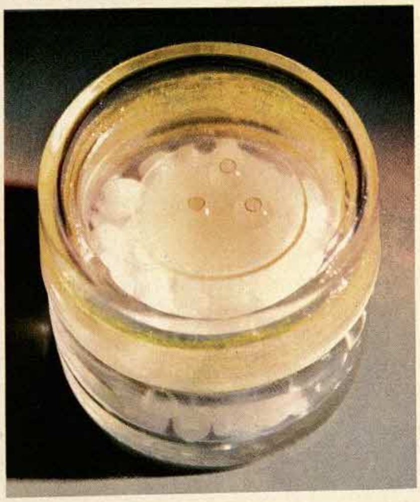


REMOVING THE HOLDERS FROM THE WATER—To pick up the holders, the technician places a piece of clean, absorbent paper on the surface of the water. The film and the holders cling to the wet paper, which is then lifted out and dried in a desiccator. Once they are dry, the film-covered wire disks are easily detached from the paper.

MOUNTING A SECTION ON A HOLDER—Using very delicate tweezers, the technician lowers one holder onto the water-filled trough on the ultramicrotome, where one ultrathin section sliced from the specimen is floating. The section adheres to the film that covers the wire mesh.



STAINING THE SPECIMEN—Some biological materials have enough contrast to give a clear image under the electron microscope. Other materials need staining with heavy metallic salts to strengthen contrast. Salts are used because they are soluble in water and can impregnate the biological material. Heavy metals are used because they exert a strong braking effect on electrons, and increase electron scattering. Substances commonly used are tungsten and lead salts. One or more drops of the solution are placed on each holder, and the prepared specimens are allowed to dry.



ARMOR FOR THE SPECIMEN—To protect the fragile tissue from bombarding electrons inside the microscope, a thin film of carbon (graphite) is evaporated onto the preparation. Inside a glass bell from which air has been removed, the holder and section are exposed to the electrodes of an electric arc. The graphite of the electrodes sublimes at a temperature of 3,500° to 4,000° C (6,332° to 7,232° F) and is deposited on the specimen.

THE COMPLETED PREPARATIONS—A single sample of tissue may yield a great many preparations. If the sections are studied in the order in which they were cut, they provide the observer with an opportunity to reconstruct a three-dimensional view of the original structure. It is well to have a large number of preparations, because some may be destroyed by exposure to the electron beam. The ones shown in this photograph are far from identical—they are of differing thicknesses and intensity of coloration. A preliminary observation will enable the operator to choose the ones that show best the special characteristics in which he is interested. This photograph shows the holders arranged on white paper, ready to be picked up with tweezers and introduced into the microscope. To protect them from dust and humidity, they are kept in a covered glass box.

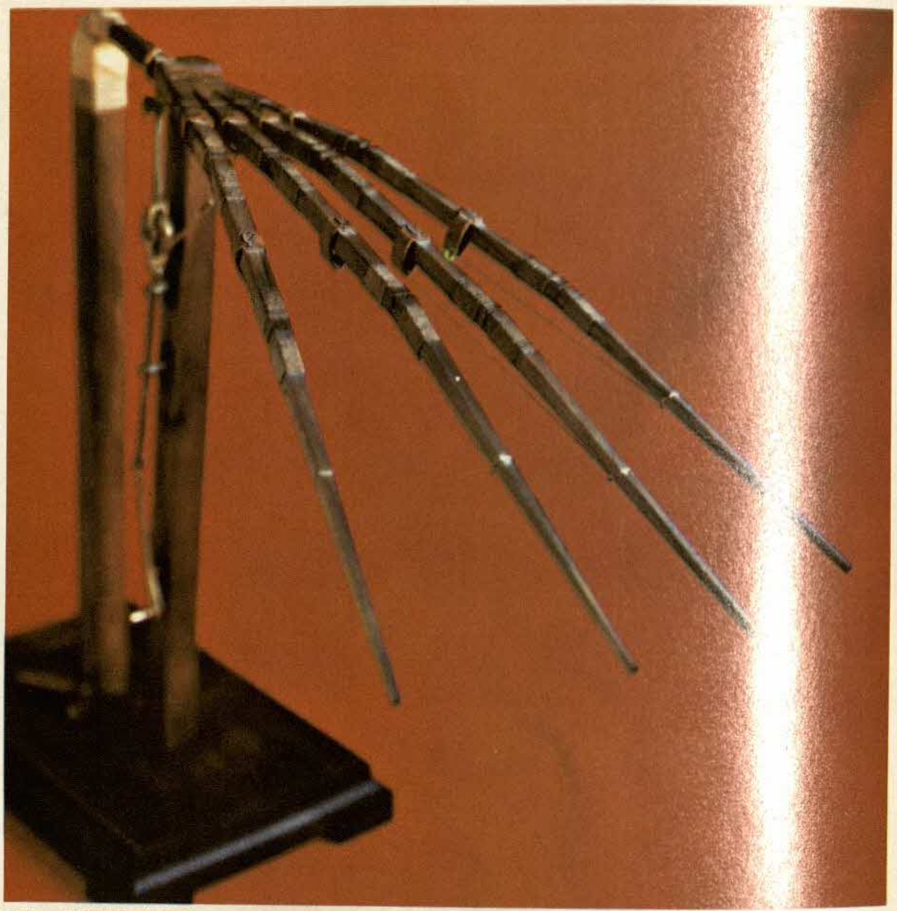
BIONICS | living systems as models for man-made systems

Man has always been intrigued by the possibility of building machines or mechanical devices based on the structure of animals that can fly, swim, jump, see, hear, or smell better than he can. Some of the best-known examples are Leonardo da Vinci's studies of flying machines, modeled after the wings of bats and birds. If sufficiently powerful engines had been available in da Vinci's time, it is quite possible that his machines could have flown. Other less spectacular examples are the streamlined shapes of submarines and the fuselages of airplanes, so like the streamlining of whales, many fish, and birds. More recently, biologists, with the cooperation of engineers, physicists, and mathematicians, have been constructing simplified models that can reproduce some of the fundamental functions of living systems. Such studies of analogies between living systems and machines have led to the development of two new sciences—bionics and cybernetics.

The word *bionics* comes from the combination of the two words, biology and electronics. *Cybernetics* comes from a Greek word meaning "governor" or "guide." The two sciences are in fact two aspects of one science. The aim of bionics is the construction of mechanical systems based on living systems, while the aim of cybernetics is the mathematical analysis of the flow of information in electronic, mechanical, and biological systems. The two studies are, therefore, complementary to each other. As yet no formal research is going on in bionics and universities do not give degrees in this new science, which was formally initiated in 1960. However, bionics goes on whenever a biologist and an engineer or physicist meet to share scientific experiments.

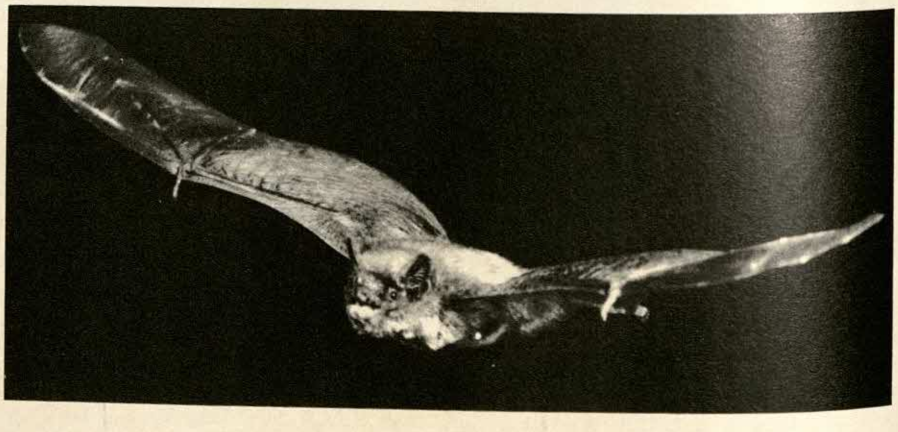
While cybernetics develops and analyzes the content of information by means of computers, bionics is concerned with improving the means of acquiring that information. Bionics may lead to improvements in computers along the lines of the human brain, an organ far superior

1a



THE FLYING MACHINE AND THE BAT'S WING—In inventing machines, men have always been inspired by nature. Thus, the flight of birds and bats has suggested numerous designs for flying machines. Leonardo da Vinci's drawings of flying machines undoubtedly provide the most famous examples. Illustration 1a is a model of a wing, built according to one of Leonardo da Vinci's sketches for a flying machine. Illustration 1b is a bat in flight.

1b



2

THE BAT AND RADAR—The bat (shown in Illustration 2a hanging by its hind legs in its usual resting position from the wall of a cave) utilizes a remarkable method of avoiding objects in the dark. Bats produce ultrahigh-frequency sound waves that bounce off any nearby object. The echoes of these waves inform the bat of the location and distance of nearby objects. This method is so sophisticated and sensitive that it even works in a cave with many hundreds of bats flying around. Modern research is endeavoring to discover exactly how the bat recognizes the echo from its own sound wave emissions. To measure the electrical potential of the individual acoustic nerve fibers of bats, microelectrodes have been inserted in the acoustic nerve. Another way of attacking the problem is to stimulate the hearing apparatus with the sounds of other bats in order to isolate areas in the brain where the signals are sorted out. Studies of the bat's echo device helped in the development of radar.

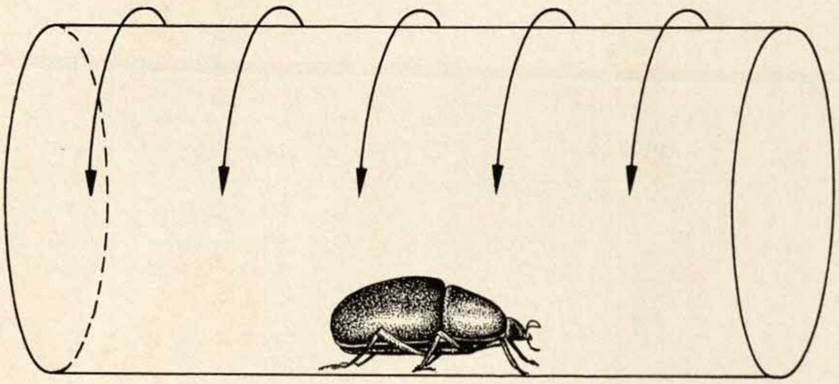
Illustration 2b shows a Navy ship equipped with radar. The radio waves produced by the radar transmitter are analogous to the ultrahigh-frequency sound waves produced by bats. After the returning waves are received they are made visible on a radar screen. "Radar" stands for *RA*dio *D*etecting *A*nd *R*anging.

to any computer in its ability to analyze information, to remember, and to operate with low power consumption.

INFORMATION-GATHERING SYSTEMS IN ANIMALS

Living organisms have extraordinary means for collecting information from their environment. The bat is an example of an animal with an outstanding ability to gather information about surrounding objects in the dark. During World War II, when radar was being developed, biologists discovered that the bat had evolved an analogous system hundreds of thousands of years ago. By emitting ultrahigh-frequency sound waves that bounce off any nearby object and listening to the echoes of those waves, bats can sense the location and distance of the object. If man had understood the mechanism earlier, the technological application would have been of immediate use. Many animals have information-gathering systems that are still poorly understood by man, as for example the ability of a stork to return to its own nest of the previous year after flying many thousands of miles during its yearly migration. Another little-understood ability is that of the mosquito to perceive the hum of another mosquito at a distance of some hundreds of meters in spite of strong winds and loud noises.

Frogs provide an example of a peculiar selectivity in response to objects seen. Frogs try to eat any insect-sized object that moves in their visual field, but will starve if left sitting on a layer of fresh insects that do not fly into their visual fields. To explain this, frog brain waves



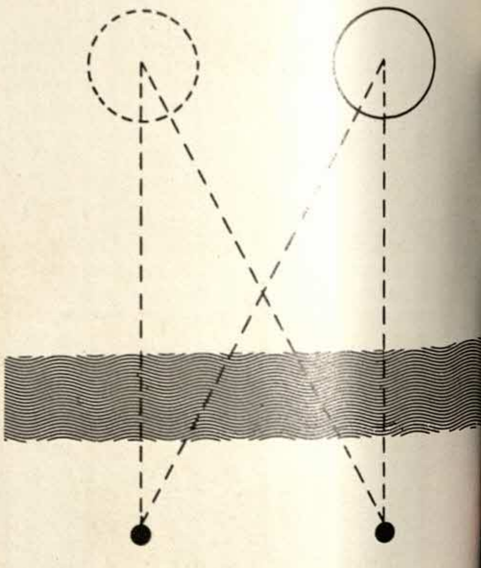
SCARABS AND THE ARTIFICIAL EYE—Scarab beetles are able to maintain their position no matter how their surroundings are moved around. If a scarab is placed in a revolving cylinder, the path it follows depends on the direction and the velocity of the light reflections produced as the cylinder rotates. This ability is due to the shape of the insect's compound eyes, which are composed of several thousand individual eyes arranged so that the whole eye somewhat resembles a cut diamond with many facets. The information obtained from each ommatidium (individual eye) is integrated with information from adjacent ommatidia so that the insect senses its direction and speed of movement. The principle underlying this integration process has been used to develop a navigational device that calculates the speed of moving rays of light. Installed in an airplane and directed toward the ground, this device registers the airplane's speed with respect to the ground.

were studied while objects of all sizes and shapes were moved in front of their eyes. In this way, two facts were established: the frog does not see insects as such, but rather objects with the dimensions of insects moving within reach of its tongue. It also sees large objects that might represent a threat, such as an approaching heron, snake, or man. In the first case, the frog is stimulated to eat the moving object within reach of its tongue; in the second case, it jumps or swims rapidly away, attempting to find a hiding place. These observations were of use when an electronic eye was being engineered, capable of distinguishing only a given type of moving object, while ignoring all others. The most important use of this device is in a radar set that selects only a given type of target.

In recent years, electronic technology has made enormous advances, especially in the field of micro-miniaturization. Integrated circuits are now being manufactured that provide a great improvement in reliability, a reduction of the physical dimensions of circuits, extended response to high frequencies, and reduced operating time. A fairly precise system of navigation that uses the moon or the stars as reference points has been built using such advanced electronic technology. The system is built in such a way that it can be installed in an airplane or in a missile. With recent techniques of miniaturization, such equipment weighs only 2 kg (about 4.5 lbs). A somewhat analogous device, however, already existed in sand flies and some moths that can orient themselves with respect to light from the moon. The compound, hemispheric insect eye with its many lenses can sense from which direction light is coming. The distance of the moon or stars is so great that light rays coming from them are practically parallel; therefore, these nocturnal animals can sense that they are moving in a straight line when light continues to impinge on the same portion of the eye. When the direction of movement is changed, light stimulates nerves coming from other parts of the eyes. These nerves, going to the brain, inform the insect of the changed direction.

Another example illustrating the possibilities of bionics is the odor-detecting apparatus of some insects. The male of the silkworm moth identifies and finds a female by her odor. His extremely sensi-

4



NAVIGATION SYSTEM OF THE SAND FLY—Some insects, including the sand fly, have evolved a system of navigation that utilizes moonlight as a reference point. This system, which involves the insect's compound eyes and brain, is much smaller than any that man has yet built.

tive sense of smell is capable of perceiving the presence of one or two odor molecules in the air. The human sense of smell requires a much larger number of molecules in order to react. An electronic device with a sensing mechanism as sensitive as the silkworm moth's sense of smell could be used for detecting gases and for making laboratory analyses by means of odor components that could not otherwise be distinguished. Such a device might be capable of distinguishing and recognizing people with a greater precision than can a police dog. It could also be used to identify damaged food long before it started to deteriorate.

The rattlesnake provides a final example of miniaturized information-gathering devices that man may someday be able to copy mechanically. Rattlesnakes, like all other pit vipers, have a pair of pits located between the nostrils and the eyes. These pits are lined with sensory cells, up to a thousand per square millimeter, that can detect changes in the temperature of the environment as far as a foot and a half away. In this way the rattlesnake locates its warm-blooded animal prey in the dark or if blinded. Man has not yet devised a micro-miniaturized sensor having so many sensory units in such a minute area, especially one that does not require amplification.

Bionicists are studying the extreme sensitivity of receptor organs, the retrieval capability of the central nervous system, the huge information storage potential of chromosomes, and decision-making circuits in some lower animals.

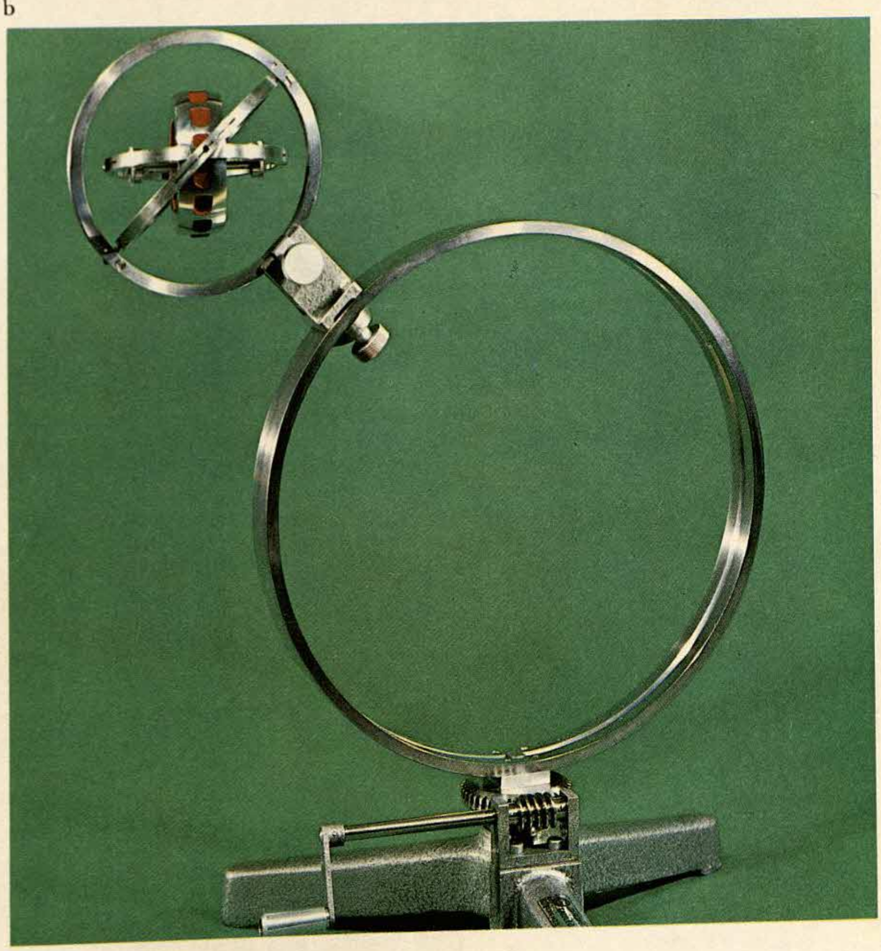
5

FLIES AND THE GYROSCOPE—A fly (Illustration 5a) has only one pair of wings. In place of the second pair that most insects have, the fly has a pair of stubby, vestigial wings called halteres or balancers. When a fly is flying, it is stable in the antero-posterior, or "pitch," plane and more or less so in the "roll" plane, but it is unstable in the horizontal, or "yaw," plane. Stability or equilibrium in this plane is maintained by patches of sensory cells located at the base of the halteres. Information received here and also from the eyes enables the fly to maintain a horizontal position in flight. If the halteres are removed, many species of flies are unable to fly. In a sense, it can be said that the halteres are "gyroscopic" sense organs, adapted to perceive deviation from the plane of their vibration.

Illustration 5b shows a rotating stabilization gyroscope. Although insect "gyroscopes" are not constructed at all like man-made gyroscopes, their function is somewhat similar. Very small gyroscopes keep airplanes and rockets on course.

a

b



ABBREVIATIONS

A	ampere
Å	Ångstrom unit
abs	absolute
a-c	alternating current (as an adjective)
amu	atomic mass unit
atm	atmosphere
at. wt	atomic weight
AU	astronomical unit
avdp	avoirdupois
Bev	one billion electron volts
bhp	brake horsepower
bhp-hr	brake horsepower-hour
bp	boiling point
Btu	British thermal unit
C	temperature Celsius; temperature Centigrade
c	candle
cal	calorie
cfm	cubic feet per minute
cfs	cubic feet per second
cgs	centimeter-gram-second (system)
cl	centiliter
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
coef	coefficient
colog	cologarithm
cos	cosine
cot	cotangent
cp	candlepower
csc	cosecant
cu	cubic
cu ft	cubic foot
db	decibel
d-c	direct current (as an adjective)
doz	dozen
E	electromotive force
e	the base of the system of natural logarithms
ev	electron volt
F	temperature Fahrenheit
fp	freezing point
fpm	feet per minute
fps	feet per second
ft	foot; feet
ft^2	square foot
ft^3	cubic foot

ft-c	footcandle
ft-lb	foot-pound
G	universal gravitational constant
g	gram
gal	gallon
g-cal	gram-calorie
gpm	gallons per minute
gps	gallons per second
hr	hour
$h\nu$	photon energy
hp	horsepower
Hz	hertz (cycles per second)
I	electric current
ID	inside diameter
in.	inch
$in.^2$	square inch
$in.^3$	cubic inch
in.-lb	inch-pound
ips	inches per second
j	joule
K	temperature Kelvin (absolute)
kcal	kilocalorie
kg	kilogram
kg-cal	kilogram-calorie
kg-m	kilogram-meter
kg/m^3	kilograms per cubic meter
kgps	kilograms per second
km	kilometer
kv	kilovolt
kw	kilowatt
kwhr	kilowatt-hour
l	liter; lumen
lat	latitude
lb	pound
lb-ft	pound-foot
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lb-in.	pound-inch
l-hr	lumen-hour
lin ft	linear foot
log	logarithm (common)
log_e	logarithm (natural)
long.	longitude
m	meter; minute (time, in astronomical circles)

m^2	square meter
m^3	cubic meter
ma	milliampere
Mev	one million electron volts
mg	milligram
mh	millihenry
mi	mile
mi^2	square mile
min	minute
m-kg	meter-kilogram
ml	milliliter
mm	millimeter
mm^2	square millimeter
mm^3	cubic millimeter
$m\mu$	millimicron
mph	miles per hour
mphps	miles per hour per second
mv	millivolt
N	Avogadro's constant
$n!$	factorial n
OD	outside diameter
oz	ounce
pH	rating on acid-alkaline scale
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
R	temperature Reaumur; resistance
RA	right ascension
rpm	revolutions per minute
rps	revolutions per second
sec	secant; second
sin	sine
sp gr	specific gravity
sq	square
tan	tangent
V	volt
VA	volt-ampere
W	watt; work
yd	yard
yd^2	square yard
yd^3	cubic yard

SCIENTIFIC SYMBOLS AND ABBREVIATIONS

α	alpha particle
β; β^-	beta particle
β^+	positron
γ	gamma radiation
Δ	a small change; heat
λ	wavelength; radioactive-decay constant
ma	milliampere
μc	microcurie
μf	microfarad
μin.	microinch
μm	micron
$\mu\mu$	micromicron
$\mu\mu$f	micromicrofarad
ν	frequency; neutrino
π	3.14159; osmotic pressure

Σ	the sum of
σ	nuclear cross section (barns); area
Ω	electrical resistance (ohms)
ω	angular speed; angular velocity
$'$	minute (angular measure)
$''$	second (angular measure)
♂	male
♀	female
$>$	is greater than
$<$	is less than
$\propto$	is proportional to
∞	infinity
$\sqrt{\ }$	square root of
$^\circ$	degrees; temperature; angle measurement (example, 30°)

[ ]	molar concentration
$+$	positive electric charge; mixed with; plus
$-$	negative electric charge; single covalent bond; minus
$=$	equals; double covalent bond; produces
$\neq$	does not equal
$\equiv$	triple covalent bond
$\rightarrow$	produces; forms; chemical reaction
$\rightleftarrows$	reversible chemical reaction
$\uparrow$	gas produced by a chemical reaction
$\downarrow$	precipitate produced by a chemical reaction
$^\bullet$	radioactive substance (follows symbol of element; example, $Cl^\bullet$)

THE
ILLUSTRATED SCIENCE
DICTIONARY

Blowpipe to Chemical Change

KEY TO PRONUNCIATION

The diacritical marks are:

ə	b*a*nan*a*, *a*but	e	b*e*t	th	*th*in
ᵊ	preceding l, m, n as in batt*le*	ē	b*ea*t	t͟h	*th*en
ə̇	*e*lectric	i	t*i*p	ü	r*u*le, f*oo*l
ər	f*ur*ther	ī	b*i*te	u̇	p*u*ll, w*oo*d
a	m*a*t	j	*j*ob, *g*em	ue	German h*ü*bsch
ā	d*ay*	ŋ	si*ng*	u͞e	French r*ue*
ä	c*o*t, f*a*ther	ō	b*o*ne	yü	*u*nion
au̇	n*ow*, *ou*t	ȯ	s*aw*, *a*ll	zh	vi*si*on
		ȯi	c*oi*n		

ˈ mark preceding the syllable with strongest stress.
ˌ mark preceding a syllable with secondary stress.

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blowpipe \'blō-ˌpīp\ *n.*

CHEMISTRY. A small, tubular device with a jet opening, used to force air or gas into a flame in order to intensify and concentrate its heat.

A BLOWPIPE *may be used in making a chemical analysis.*

BLOWPIPE

blueprint \'blü-ˌprint\ *n.*

ENGINEERING. A photographic print in white on a blue background, or blue on a white background, used as an exact and detailed outline of architectural or engineering plans.

A BLUEPRINT *is produced by a photochemical process.*

bog \'bäg or 'bȯg\ *n.*

EARTH SCIENCE. Wet, spongy ground that contains decayed moss and other vegetable matter; a swamp.

Grasses, sedges and mosses are typical of the vegetation in a BOG.

boil \'bȯi(ə)l\

1. PHYSICS (V.) To vaporize a liquid with accompanying bubbling, by the application of heat or reduction of pressure, or both. 2. MEDICINE (N.). An inflamed, painful swelling of the skin that is pus-filled and caused by infection.

A liquid can be made to BOIL *at a lower temperature by reducing the atmospheric pressure on its surface.*

boiling point \'bȯi(ə)l-iŋ 'pȯint\

PHYSICS. The temperature at which a liquid boils, or the temperature at which the vapor pressure of a liquid equals the atmospheric pressure on the liquid.

The BOILING POINT *of any liquid varies with the atmospheric pressure on that liquid.*

bolide \'bō-ˌlīd\ *n.*

ASTRONOMY. A brilliant meteor, particularly one that explodes.

A BOLIDE *is sometimes referred to as a fireball.*

boll \'bōl\ *n.*

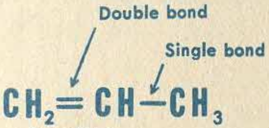
BOTANY. The pod of a plant, particularly of cotton or flax.

The larva of the boll weevil is hatched in the BOLL *of a cotton plant.*

bombardment \bäm-'bärd-mənt\ *n.*

PHYSICS. A stream of rapidly-moving particles, such as electrons, neutrons or other subatomic particles, directed at atomic nuclei.

BOMBARDMENT occurs in a nuclear reactor.



BOND

bond \\'bänd\\ *n.*

CHEMISTRY. The electrical attraction caused by the distribution of electrons around the nuclei of the atoms that are held together.

In chemical formulas, a double BOND is indicated by a double line (=) or two dots (:).

bone \\'bōn\\ *n.*

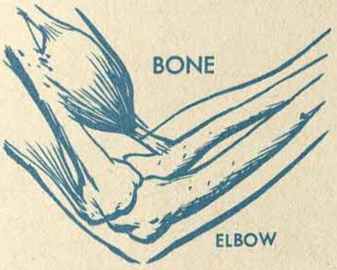
ANATOMY and ZOOLOGY. Any hard piece or part of the skeleton of vertebrate animals.

A soft tissue in the BONE, called marrow, manufactures blood.

Boolean algebra \\'bü-lē-ən 'al-jə-brə\\

MATHEMATICS. A system of logical propositions denoted by symbols and subjected to abstract mathematical operations that correspond to the laws of logic.

George Boole, an English mathematician, developed BOOLEAN ALGEBRA.



booster rocket \\'bü-stər 'räk-ət\\

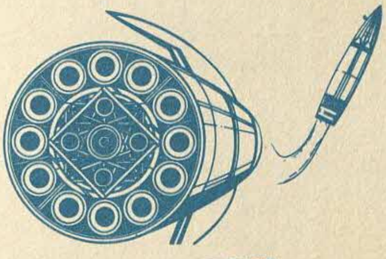
ASTRONAUTICS. An auxiliary rocket that is used to assist in the takeoff of a larger rocket.

The thrust from a BOOSTER ROCKET, though of great intensity, lasts for only a short period.

booster shot \\'bü-stər 'shät\\

MEDICINE. An additional injection of a vaccine given after a specified period to maintain an immunity developed by a previous injection.

Physicians commonly give a BOOSTER SHOT for tetanus every three years.



BOOSTER ROCKET

borate \\'bȯr-ˌāt\\ *n.*

CHEMISTRY. A salt or ester of boric acid.

The common compound borax is a BORATE.

borax \\'bō(ə)r-ˌaks\\ *n.*

CHEMISTRY and EARTH SCIENCE. $Na_2B_4O_7 \cdot 10H_2O$. A colorless or white crystalline salt; an ore of boron.

BORAX is used in the manufacture of such household items as soaps, enamel and glass.

boreal \'bōr-ē-əl\ *adj.*

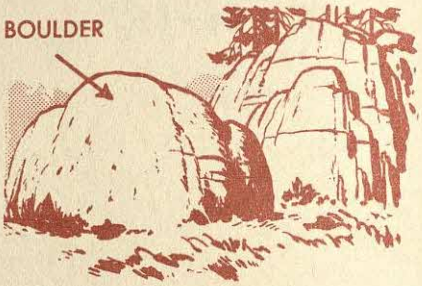
EARTH SCIENCE. Northern, or pertaining to Boreas, the north wind.

The North Pole is the BOREAL *pole.*

boric acid \'bōr-ik 'as-əd\

CHEMISTRY. H_3BO_3. A white, crystalline, mildly acid compound used as an antiseptic and in the manufacture of many products, such as cements, enamels and glass.

BORIC ACID *is often used in a three percent solution as an eyewash.*



boron \'bō(ə)r-ˌän\ *n.*

CHEMISTRY. A nonmetallic chemical element occurring naturally only in combination and produced either as a brown, amorphous powder or as very hard crystals. Symbol, B; atomic number, 5; atomic weight, 10.82.

An alloy of BORON *and iron is used to make the control rods in some nuclear reactors.*

botanist \'bät-ᵊn-əst\ *n.*

BOTANY. A scientist who studies the structure, life processes, relationships and distribution of plants on the earth.

Luther Burbank, a famous BOTANIST, *performed many useful experiments with plants.*

botany \'bät-ᵊn-ē\ *n.*

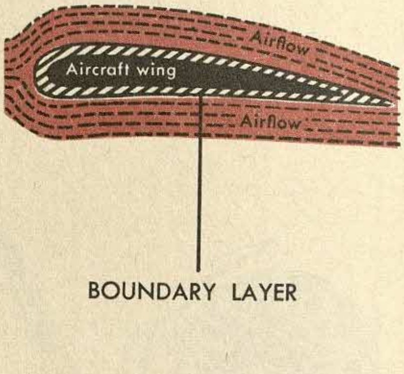
The branch of biology that deals with the life, structure, growth and classification of plants.

The study of BOTANY *is generally part of the preparation for a career in agriculture or forestry.*

boulder \'bōl-dər\ *n.*

EARTH SCIENCE. Any detached, large rock that has been rounded or worn by weather and water; a rock greater than 256 mm. (approximately 10 inches) in diameter.

A glacier may transport a BOULDER *weighing several tons for great distances.*



BOUNDARY LAYER

boundary layer \'bau̇n-d(ə-)rē 'lā-ər\

PHYSICS. In a fluid moving over a surface, a thin layer of decreased velocity closest to the surface. The decreased velocity is caused by the friction of the fluid as it contacts the surface.

To reduce drag of the air BOUNDARY LAYER, *one type of aircraft wing sucks in air through small slots in the wing.*

Boyle's law \'bȯi(ə)lz 'lȯ\

PHYSICS. A law of physics stating that the product of the volume and the pressure of a given mass of a gas (pv) is constant at a given temperature.

BOYLE'S LAW *is named for the English physicist and chemist, Robert Boyle.*

brace roots \'brās 'rüts\

BOTANY. Prop or supporting roots.

Corn is a common plant that has BRACE ROOTS.

brachial \'brak-ē-əl\ *adj.*

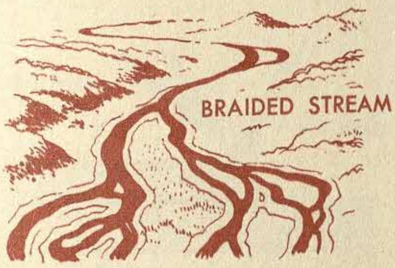
ANATOMY. Pertaining to the arm, an armlike part or an armlike process.

The chief artery of the upper arm is called the BRACHIAL *artery.*

brachistochrone \bra-'kis-tə-ˌkrōn\ *n.*

PHYSICS. A cycloidal curve or path along which a body, under the influence of gravity alone, will fall from one point to another in the shortest time.

A common physics experiment involves comparing the time of descent of a marble along a path shaped like a BRACHISTOCHRONE *and along an inclined plane.*



braided stream \'brād-əd 'strēm\

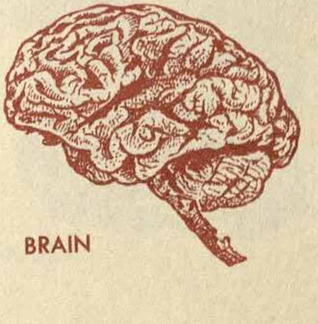
EARTH SCIENCE. A stream that is divided into or follows an interlocking system of channels separated by sandbars or islands.

A BRAIDED STREAM *is formed when more sediment is washed into the stream than can be carried away.*

brain \'brān\ *n.*

PHYSIOLOGY and ZOOLOGY. A large mass of nerve tissue that serves as the center of voluntary movement and coordination in man and other vertebrates; the part of the nervous system where memory, reasoning and other mental processes occur. In vertebrates, the brain is enclosed in a skull at the upper end of the spine.

The average weight of the BRAIN *of the human male is close to three pounds.*



brain wave \'brān 'wāv\

MEDICINE *and* PHYSIOLOGY. Rhythmic electrical impulses given off by the nerve centers in the brain and spinal cord.

A BRAIN WAVE *can be measured by an instrument called an electroencephalograph.*

braking ellipse \'brāk-iŋ i-'lips\

ASTRONAUTICS. The successively smaller orbits a spacecraft follows in returning to earth from space. At a point on each orbit, the spacecraft loses speed through friction with the earth's atmosphere until it has lost enough speed to enter the atmosphere safely.

A spacecraft in a BRAKING ELLIPSE *loses some of its heat as it leaves the earth's atmosphere once during each orbit.*

BRAKING ELLIPSE

branch \'branch\ *n.*

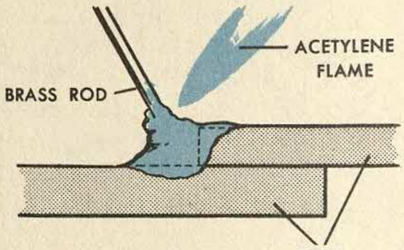
1. EARTH SCIENCE. A tributary stream that runs into a larger waterway. 2. ANATOMY. Any arm or part extending from the main body. 3. BOTANY. A short or secondary woody extension growing from the main stem of a tree. 4. ENGINEERING and MATHEMATICS. The way that a digital computer chooses, out of two or more possible ways, to solve a problem as the most logical way.

The Missouri River is the longest BRANCH *of the Mississippi River.*

brass \'bras\ *n.*

CHEMISTRY. A yellowish alloy made of copper and zinc combined in varying proportions.

BRASS *is used in making such musical instruments as the tuba and the trombone.*



BRAZE

braze \'brāz\ *v.*

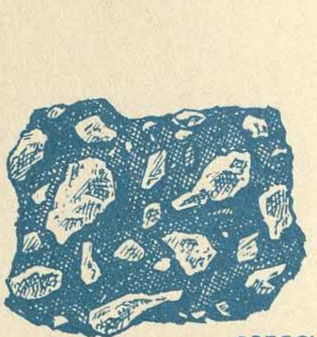
ENGINEERING. To join two metals or alloys by a type of welding operation using a relatively high-melting, nonferrous metal or alloy to bind the two parts together.

Silver alloys, brasses and bronze are often used to BRAZE.

breccia \'brech-(ē-)ə\ *n.*

EARTH SCIENCE. A rock composed of sharp-cornered fragments that are cemented together by sand, clay or lime.

BRECCIA *is produced by the grinding and crushing of rocks in a fault.*



BRECCIA

breed \'brēd\ *n.*

BIOLOGY. A type of animal or, sometimes, plant, distinguished by having certain features that remain the same generation after generation; a variety or race of animal.

The dachshund is a BREED *of dog that is noted for its short legs and long body.*

breeder reactor \'brēd-ər rē-'ak-tər\

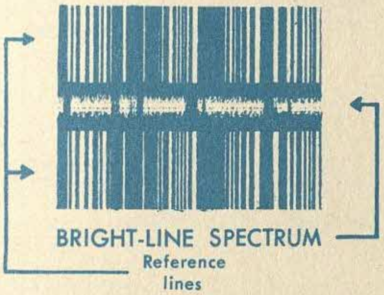
PHYSICS. A reactor that produces more atomic fuel than it consumes.

Plutonium is produced from uranium in a BREEDER REACTOR.

breeding range \'brēd-iŋ 'rānj\

ZOOLOGY. That portion of an animal's geographic habitat in which reproduction normally occurs.

The BREEDING RANGE *of the American catbird extends from British Columbia south to the Gulf of Mexico.*



BRIGHT-LINE SPECTRUM

bright-line spectrum \'brīt ˌlīn 'spek-trəm\

PHYSICS. An emission spectrum having bright lines against a dark background.

By using the spectroscope, scientists can identify the elements represented in a BRIGHT-LINE SPECTRUM.

bright nebula \'brīt 'neb-yə-lə\

ASTRONOMY. A cloud of dust and gas in space that is illuminated by the light from a nearby star.

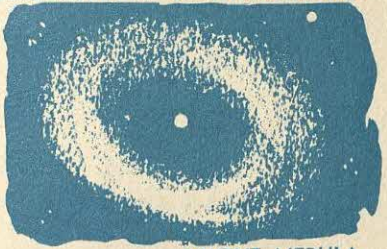
The famous Ring Nebula, in the constellation Lyra, is an example of a BRIGHT NEBULA.

brine \'brīn\ *n.*

CHEMISTRY. A concentrated salt solution.

Salt is generally mixed with the ice in a home ice-cream freezer to produce a BRINE *with a temperature below 0° C.*

RING NEBULA IN CONSTELLATION LYRA



BRIGHT NEBULA

British thermal unit \'brit-ish 'thər-məl 'yü-nət\

CHEMISTRY and PHYSICS. The quantity of heat necessary to raise the temperature of one pound of water one degree F.; *abbr.* Btu.

The BRITISH THERMAL UNIT *has 252 calories.*

brittleness \'brit-ᵊl-nəs\ *n.*

PHYSICS. The property of a material that causes it to fracture under slight bending or deforming.

BRITTLENESS *is a characteristic of certain alloys of steel.*

bromide \'brō-ˌmīd\ *n.*

CHEMISTRY. A compound of bromine and another element.

Silver BROMIDE *is much used in photography.*

bromine \'brō-ˌmēn\ *n.*

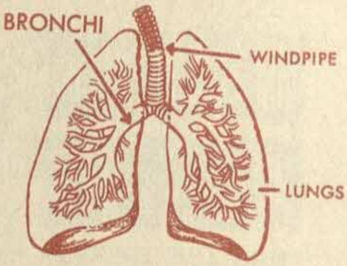
CHEMISTRY. One of the halogen group of elements, closely resembling chlorine, that is in the form of a reddish-brown vapor and has an unpleasant odor. Symbol, Br; atomic number, 35; atomic weight, 79.91.

A compound of BROMINE *is used in antiknock motor fuel.*

bronchi \'brän-ˌkī\ *n.*

ANATOMY. The two main branches of the trachea, or windpipe, that lead to the lungs.

A bronchoscope is used to examine and treat the inside of the BRONCHI.



bronze \'bränz\ *n.*

CHEMISTRY. An alloy of copper and tin that sometimes has small proportions of other elements, such as zinc or phosphorus.

The various uses of BRONZE *depend upon the properties produced by the proportions of its ingredients.*

Brownian motion \'brau̇-nē-ən 'mō-shən\

PHYSICS. The constant, rapid, random movement of suspended colloidal particles, caused by collision with molecules of the fluid surrounding the particles.

Dr. Robert Brown, a Scottish botanist, first demonstrated BROWNIAN MOTION.

bruise \'brüz\ *n.*

BIOLOGY. An area of discoloration, usually brown or black, on the skin of an animal or fruit, caused by a blow that does not break the skin.

In man, a BRUISE *around the eye is called a black eye.*

Brunton compass \'brən-tən 'kəm-pəs\

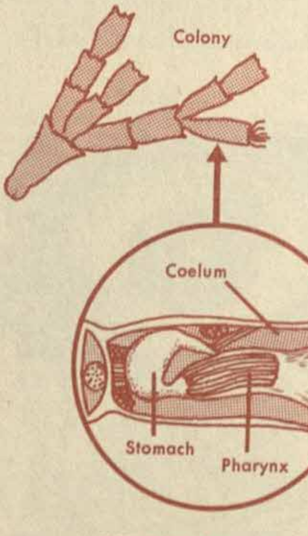
EARTH SCIENCE. A small pocket compass with a sighting device and reflector attached.

The BRUNTON COMPASS *is used by geologists to determine direction and to measure the attitude or angle of rock strata.*

bryozoan \ˌbrī-ə-'zō-ən\ *n.*

BIOLOGY. A zooid belonging to a small phylum of aquatic animals that reproduce by budding and usually form colonies.

A BRYOZOAN *has a true coelom.*



BRYOZOAN

Btu

The abbreviation for British thermal unit. See *British thermal unit.*

BUBBLE CHAMBER

Path of beta particle in bubble chamber within a magnetic field

bubble chamber \'bəb-əl 'chām-bər\

PHYSICS. A chamber in which an atomic particle is passed through a superheated liquid to produce a path of bubbles along its track. The track is then photographed and studied.

The liquid hydrogen BUBBLE CHAMBER *is a recently-developed instrument for nuclear track recording.*

bud \'bəd\ *n.*

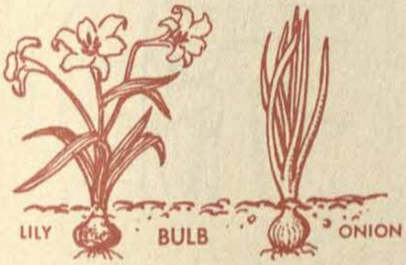
BOTANY. A small, undeveloped stem or shoot of a plant from which leaves or flowers develop.

A BUD *is often covered by outer leaves.*

buffer \'bəf-ər\ *n.*

CHEMISTRY. Any substance that tends to prevent a change in composition, particularly the hydrogen ion concentration of a solution.

A BUFFER *maintains the hydrogen ion concentration of a solution through the common-ion effect.*



buffer salt \'bəf-ər 'sȯlt\

CHEMISTRY. A salt used to make a solution, usually a weakly-ionized acid or base, whose acidity or basicity is not changed when a small amount of acid or a base is added.

Blood contains BUFFER SALT.

bulb \'bəlb\ *n.*

BOTANY. A thickened, fleshy plant bud, usually underground, that has overlapping, scalelike leaves, and in which food reserves are stored; for example, the bulbs of the onion and the lily.

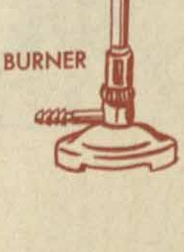
People sometimes mistakenly call the corm of the crocus and gladiolus, or the tuber of the potato and dahlia, or the rhizome of certain irises and ferns, a BULB.

Bunsen burner \'bən(t)-sən 'bər-nər\

CHEMISTRY. A small gas burner consisting of a hollow metal tube with adjustable holes to admit air and producing a hot flame when lighted.

The flame produced by a BUNSEN BURNER *is regulated by adjusting the mixture of gas and air.*

BUNSEN BURNER



buoyancy \'bȯi-ən-sē\ *n.*

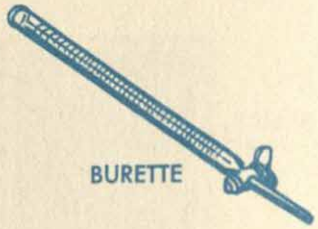
PHYSICS. The ability to float on the surface of a liquid, or the upward force on a floating or submerged object.

Although the density of steel is seven times that of water, steel ships have BUOYANCY *because they are hollow.*

burette \byu̇-'ret\ *n.*

CHEMISTRY. A graduated, cylindrical glass tube with a small opening and a stopcock at the bottom. It is used by chemists to measure small quantities of liquid or gas.

A BURETTE *is standard equipment in a well-equipped chemistry laboratory.*



bursa \'bər-sə\ *n.*

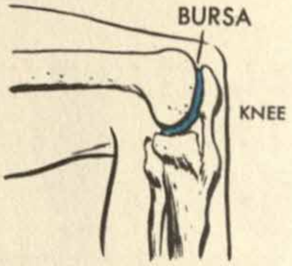
ANATOMY. A sac or pouchlike cavity filled with a viscid (sticky) fluid, especially between joints.

A BURSA *is located at a place where friction would otherwise develop.*

bushel \'bu̇sh-əl\ *n.*

MATHEMATICS. A unit of dry measure equal to 4 pecks, or 32 quarts.

Large quantities of potatoes are sold by the BUSHEL.



butane \'byü-ˌtān\ *n.*

CHEMISTRY. C_4H_{10}. Either of two inflammable, gaseous hydrocarbons in the methane series that have the same formula but different structures, depending on how each carbon atom links with the other three.

BUTANE *is found in petroleum and natural gas.*

butte \'byüt\ *n.*

EARTH SCIENCE. A large hill, isolated by erosion and having steep sides and a small, flat, pointed or rounded top; also, a mesa greatly reduced in size by erosion.

A BUTTE *can tower hundreds of feet above a valley floor.*

butyl rubber \'byüt-ᵊl 'rəb-ər\

CHEMISTRY. A synthetic rubber, polyisobutylene, highly resistant to chemicals and physical abrasion.

BUTYL RUBBER *is used in making automobile tires.*

butyric acid \byü-'tir-ik 'as-əd\

CHEMISTRY. C_3H_7COOH. Either of two colorless isomeric acids having an unpleasant odor.

Normal BUTYRIC ACID *is found in rancid butter and in perspiration.*

by-product \'bī-ˌpräd-(ˌ)əkt\ *n.*

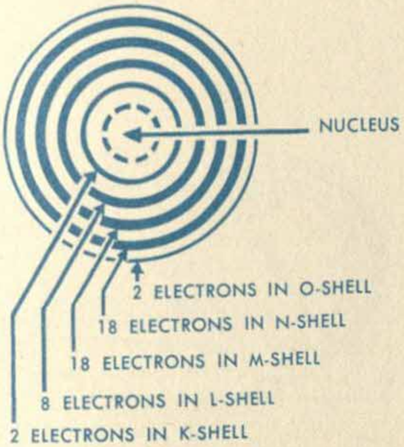
CHEMISTRY. A secondary or incidental substance produced in the course of making a primary substance.

The fertilizer ammonium sulfate is one BY-PRODUCT *of the coke industry.*

C

°C.
An abbreviation for a temperature measured on the Centigrade temperature scale. See *Centigrade temperature scale.*

CADMIUM (ATOM)



cadmium \\'kad-mē-əm\\ *n.*
CHEMISTRY. A gray or blue-white metallic element, a by-product of zinc refining, that is easily molded and used as a corrosion-resistant plating for steels. Symbols, Cd; atomic number, 48; atomic weight, 112.40.

CADMIUM *is used to absorb neutrons in small nuclear reactors, as a protection against radiation.*

caisson \\'kā-ˌsän\\ *n.*
ENGINEERING. A structure, boxlike or tubelike in shape, used as a foundation in underwater construction, or as a working chamber for men employed in underwater construction.

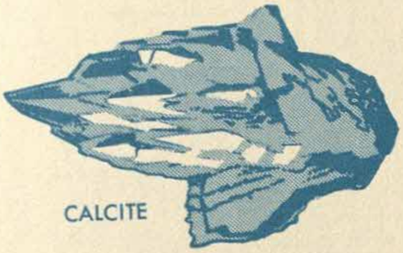
Compressed air keeps mud and water out of the working chamber of a CAISSON.

calcareous \\kal-'kar-ē-əs\\ *adj.*
CHEMISTRY and EARTH SCIENCE. Relating to materials composed of or containing calcium carbonate, $CaCO_3$.

Limestone, chalk, coquina, dripstone and dolomite are common CALCAREOUS *rocks.*

calcification \\ˌkal-sə-fə-'kā-shən\\ *n.*
1. PHYSIOLOGY. The process by which calcium salts are deposited within a tissue. 2. EARTH SCIENCE. Formation of fossils by replacement of the hard parts of a plant or animal with calcium carbonate.

CALCIFICATION *takes place in the formation and growth of the bones in the body.*



CALCITE

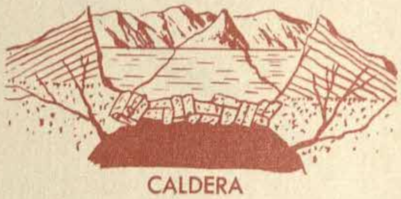
calcite \\'kal-ˌsīt\\ *n.*
CHEMISTRY and EARTH SCIENCE. $CaCO_3$. The mineral calcium carbonate that is found in various forms. One form, known as Iceland spar, consists of clear crystals that cause double refraction of light.

Chalk and limestone are forms of CALCITE.

calcium \'kal-sē-əm\ *n.*

CHEMISTRY. A silver-white, soft metallic element, always found in compound form because it is chemically very active. Symbol, Ca; atomic number, 20; atomic weight, 40.08.

Compounds containing CALCIUM, *in such foods as milk and egg yolk, are necessary for the healthy development of the teeth and bones.*



CALDERA

calculus \'kal-kyə-ləs\ *n.*

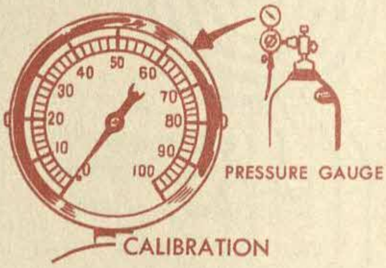
MATHEMATICS. The branch of mathematics that uses the concept of limits in the study of the rate of change or the change in the value of a function with respect to the variable or variables under observance; also, the application of these methods to the investigation of slopes of tangents to curves, of areas of surfaces bounded by curves, volumes of solids bounded by curved surfaces and to velocity and acceleration.

The main branches of elementary CALCULUS *are differential and integral calculus.*

caldera \kal-'der-ə\ *n.*

EARTH SCIENCE. A roughly-circular, usually steep-sided volcanic crater or basin having a width at least three times as great as its depth.

Crater Lake in Oregon is a CALDERA *containing an extinct volcano that now stands as a small island.*



CALIBRATION

calibration \ˌkal-ə-'brā-shən\ *n.*

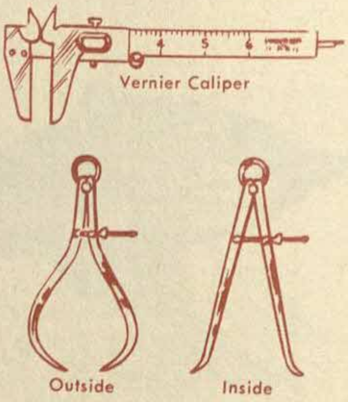
MATHEMATICS. The graduated scale or markings on various measuring instrument.

The CALIBRATION *on a gauge may indicate pounds of pressure.*

caliper \'kal-ə-pər\ *n.*

MATHEMATICS. A small hand tool having two movable legs that are joined, or one fixed and one movable jaw, as in the vernier caliper. It is used in measuring the distance between two objects, or in the diameter, thickness or length of an object.

A micrometer CALIPER, *using the principle of a screw moving in a fixed nut, permits measurements to 1/10,000 of an inch.*



CALIPER

callus \'kal-əs\ *n.*

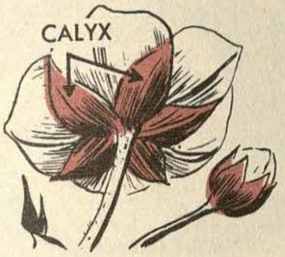
1. PHYSIOLOGY. A whitish, hardened layer of tissue on the surface of the skin. 2. MEDICINE. Tissue that is formed about the fragments of a broken bone. 3. BOTANY. Plugs of carbohydrate material that close the sieve plates of sieve tubes; also, a mass of soft parenchymatous tissue that forms over the wounded or cut surface of a stem or root.

Friction and pressure on the epidermis may stimulate cell division to produce a CALLUS *more than 100 cells thick.*

caloric \kə-ˈlȯr-ik\ *adj.*

BIOLOGY, CHEMISTRY and PHYSICS. Associated with or having to do with heat.

A knowledge of the CALORIC *value in food is necessary in planning diets.*



calorie \ˈkal-(ə)rē\ *n.*

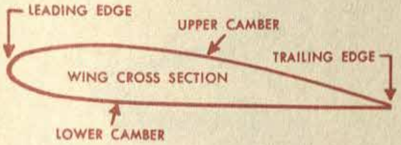
1. CHEMISTRY. A unit of heat energy equal to the amount of heat that will raise the temperature of one gram of water one degree C.; *abbr.* cal. 2. PHYSIOLOGY. The amount of heat necessary to raise the temperature of 1,000 grams (kilogram) of water one degree C. (the kilocalorie), used in measuring the heat value in foods; *abbr.* Cal. or kcal.

The CALORIE *is the unit used when temperature is measured on the Centigrade scale, while the British thermal unit is used when temperature is measured on the Fahrenheit scale.*

calorimeter \ˌkal-ə-ˈrim-ət-ər\ *n.*

CHEMISTRY and PHYSICS. A device for measuring the heat produced or absorbed in various chemical or physical reactions.

A CALORIMETER *can be used in the process of measuring the specific heat of metal.*



CAMBER

calyx \ˈkā-liks\ *n.*

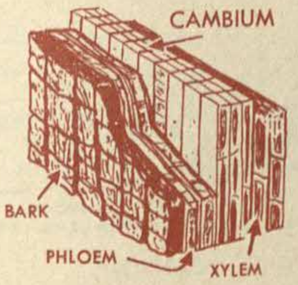
BOTANY. A term used to refer to all the sepals of a flower as a unit; see *sepal.*

The CALYX *surrounds the inner parts of a flower in the bud stage.*

camber \ˈkam-bər\ *n.*

AERONAUTICS and ENGINEERING. A convex curvature of the surface of such aircraft parts as the wing or rudder, or of a bridge structure; also, the placement of the front wheels of an automobile so that they are closer together at the bottom than at the top.

The CAMBER *of an aircraft wing can be expressed through mathematical relationships between the surface and the chord of the airfoil.*



cambium \ˈkam-bē-əm\ *n.*

BOTANY. A layer of cells in the stem and roots of woody plants. New cells formed on its inside add xylem, and new cells formed on its outside add phloem.

Because of the manner in which new cells are formed in the CAMBIUM, *the circumference of a stem increases, while there is little or no increase in the length of a stem segment.*

camphor \'kam(p)-fər\ *n.*
CHEMISTRY. $C_{10}H_{16}O$. A gumlike compound that is a saturated hydrocarbon of ketone type, obtained from the wood and bark of the camphor tree.

CAMPHOR *is used principally in making photographic films and medicines.*

canali \kə-'nä-lē\ *n.*
ASTRONOMY. The name given the canals on Mars by the Italian astronomer, Giovanni Schiaparelli, in 1877.

Percival Lowell, a famous American astronomer, devoted much of his life's work to the study of CANALI *and other surface markings on Mars.*

candlepower \'kan-dᵊl-ˌpaů(-ə)r\ *n.*
PHYSICS. A standard unit of measurement for the intensity of light; the light from a standard candle used as a basis for measuring the intensity or brightness of other light sources.

An ordinary 60-watt electric lamp is about 50 CANDLEPOWER.

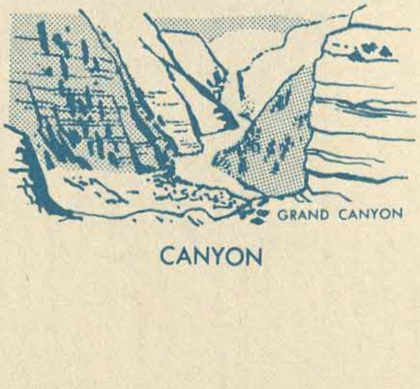
CANINE

canine \'kā-ˌnīn\ *adj.*
ANATOMY and ZOOLOGY. Referring to the pair of pointed teeth found in both the upper and lower jaws between the incisors and the bicuspids.

Carnivorous animals use the CANINE *teeth to tear and shred meat.*

canyon \'kan-yən\ *n.*
EARTH SCIENCE. A deep gorge or ravine with steep walls formed by the down-cutting of running water; also, a steep-sided, underwater valley.

A CANYON *differs from a valley in having sides that are perpendicular, or nearly so, and in being long relative to its width.*



CANYON

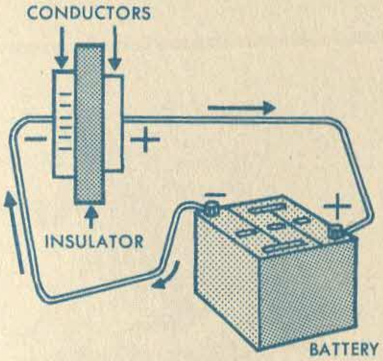
capacitance \kə-'pas-ət-ən(t)s\ *n.*
PHYSICS. The ability of a capacitor, or condenser, to store an electrical charge, expressed as the ratio of a stored charge on one conductor or plate of a capacitor to the potential between the plates.

A conductor able to store a great amount of electric charge has a very high CAPACITANCE.

capacitive reactance \kə-'pas-ə-tiv rē-'ak-tən(t)s\
PHYSICS. The impedance, sometimes called the apparent resist-

ance, of an alternating current circuit caused by the presence of a capacitor in the circuit.

CAPACITIVE REACTANCE *in an alternating current circuit causes the current to lead the voltage.*



CAPACITOR

capacitor \kə-'pas-ət-ər\ *n.*

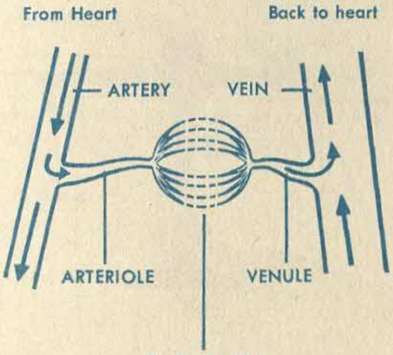
PHYSICS. An electrical device consisting of two conductors, generally parallel metal plates, separated by an insulator. Either plate is able to store an electrical charge, while the opposite charge is induced on the other plate.

The capacitance of a CAPACITOR *is commonly measured in units of microfarads.*

cape \'kāp\ *n.*

EARTH SCIENCE. A portion of land protruding into a large body of water; a headland, point or promontory.

Because it is a large area of land, a CAPE *is a prominent feature that interrupts the regularity of a coastline.*



CAPILLARY

capillarity \ˌkap-ə-'lar-ət-ē\ *n.*

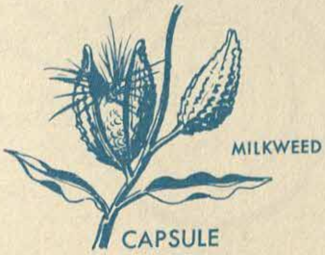
1. PHYSICS. The rising of a liquid in a small tube or capillary, caused by the adhesive force between the liquid and the wall of the tube, the adhesive force being greater than the cohesive force among the particles of the liquid; also, the falling of a liquid in a capillary, caused by a cohesive force that is greater than the adhesive force. 2. EARTH SCIENCE. The movement of water through fine spaces in soil or rock.

CAPILLARITY *takes place when water enters a space with a hair-like diameter, such as the spaces within glass tubes, wicks, blotting paper or cracks in soil and rocks.*

capillary \'kap-ə-ˌler-ē\ *n.*

1. ANATOMY. Any one of the tiny blood vessels connecting the arterioles to the venules, forming a network throughout most of the body. 2. A tube with a very small bore.

The thin walls of a CAPILLARY *allow an interchange of materials between the bloodstream and the surrounding cells.*



CAPSULE

capsule \'kap-səl\ *n.*

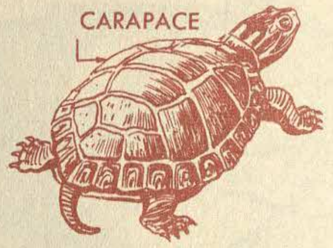
1. BOTANY. A closed structure containing seeds. 2. ANATOMY. A tissue or sac composed of membranes surrounding an organ or other part of the body. 3. ASTRONAUTICS. A compartment attached to a propelling device, such as a rocket, and designed to hold men, animals or instruments. 4. MEDICINE. A small, soluble gelatin container used to enclose medicine to be taken internally.

The CAPSULE *of a cotton or milkweed plant bursts when it is ripe.*

carapace \\'kar-ə-ˌpās\\ *n.*

ZOOLOGY. A chitinous or bony shield covering all the back or part of the back of certain animals.

The upper shell of a turtle is a CARAPACE.



carat \\'kar-ət\\

(N.). A unit of weight for gems and precious metals, standardized at 200 milligrams. (Adj.). Referring to the proportion of gold present in an alloy, each unit being 1/24 part of the alloy.

In expressing the weight of pearls, the CARAT *is divided into four grains, called carat grains.*

carbide \\'kär-ˌbīd\\ *n.*

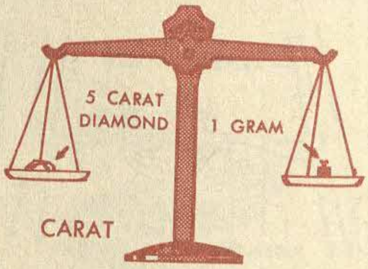
CHEMISTRY. A compound of carbon and another element.

Calcium CARBIDE, CaC_2, *reacts with water to produce acetylene,* C_2H_2, *and calcium hydroxide,* $Ca(OH)_2$.

carbohydrate \\ˌkär-bō-'hī-ˌdrāt\\ *n.*

1. CHEMISTRY. A compound composed of the elements carbon, hydrogen and oxygen. 2. BIOLOGY. A class of foods.

Sugar is a CARBOHYDRATE *that is soluble in water.*



CARAT

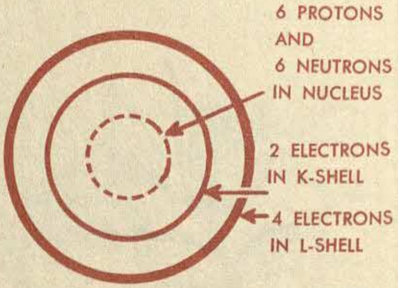
carbolic acid \\kär-'bäl-ik 'as-əd\\

CHEMISTRY. Popular term for phenol. See *phenol.*

carbon \\'kär-bən\\ *n.*

CHEMISTRY and EARTH SCIENCE. A nonmetallic element that occurs naturally, as in diamonds or graphite, or is produced by incomplete combustion, as in lampblack; a component of all organic compounds. Symbol, C; atomic number, 6; atomic weight, 12.01.

CARBON *varies in hardness, depending upon its form.*



CARBON
(CARBON 12 ATOM)

carbonate \\'kär-bə-ˌnāt\\ *n.*

CHEMISTRY. A salt or ester of carbonic acid; the anion CO_3^{--}.

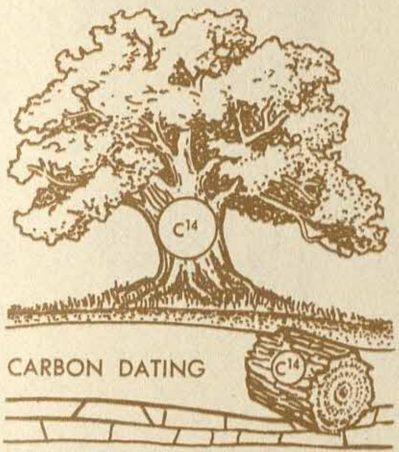
A base reacts with carbonic acid, H_2CO_3, *to form a* CARBONATE.

carbon cycle \\'kär-bən 'sī-kəl\\

1. ASTRONOMY and PHYSICS. A chain of thermonuclear fusion reactions in which C^{12} acts as a catalyst. Four hydrogen atoms are converted into one helium atom and large amounts of energy are released. 2. BIOLOGY. The cycle that involves atmospheric carbon dioxide, CO_2, and water in the photosynthesis

of carbohydrates by plants. The carbon dioxide is later released by both plants and animals during respiration and by decaying organic matter.

The CARBON CYCLE, *as proposed by the American physicist, Hans Bethe, partially explains the tremendous amounts of energy radiated by stars.*



CARBON DATING

Fossilized wood 5568 years old contains one-half as much C^{14} as wood of living tree

carbon dating \\'kär-bən 'dāt-iŋ\\

CHEMISTRY, EARTH SCIENCE and PHYSICS. A method of estimating the age of historical objects by computing the rate of their nuclear disintegration based on the amount of radioactive carbon, C^{14}, they contain.

CARBON DATING *depends on the fact that once an object is buried, it is removed from the carbon cycle in nature.*

carbon dioxide \\'kär-bən (')dī-'äk-ˌsīd\\

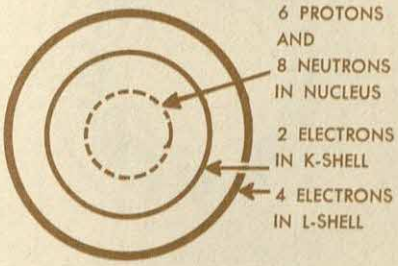
1. CHEMISTRY. CO_2. A gas produced when carbon combines with oxygen. It has no characteristic color or odor and does not support combustion. 2. BIOLOGY. A product of the oxidation of organic materials, as in respiration and decay.

CARBON DIOXIDE *in solid form is used as a refrigerant known as dry ice.*

carbon dioxide-oxygen cycle \\'kär-bən (')dī-'äk-ˌsīd 'äk-si-jən 'sī-kəl\\

BIOLOGY. An endless natural process of exchange: Carbon dioxide is used by green plants during photosynthesis and released during plant and animal respiration, and during the decay and oxidation of organic materials. Oxygen is used during animal and plant respiration, and during the decay and oxidation of organic materials, and is released during photosynthesis.

By use of radioactive or "tagged" atoms, scientists have been able to investigate many aspects of the CARBON DIOXIDE-OXYGEN CYCLE.



CARBON 14
(ISOTOPE)

carbon 14 \\'kär-bən\\

CHEMISTRY, EARTH SCIENCE and PHYSICS. A radioactive isotope of carbon that has an atomic weight of 14 instead of 12 and a known rate of disintegration (a half-life of approximately 5,568 years); see *carbon dating.*

CARBON 14 *is continuously formed in the atmosphere by the bombardment of nitrogen atoms by neutrons produced by cosmic rays from outer space.*

carboniferous \\ˌkär-bə-'nif-(ə-)rəs\\ *adj.*

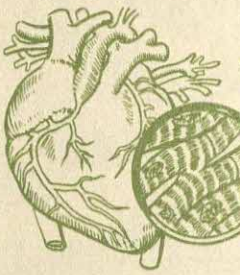
EARTH SCIENCE. Referring to the Carboniferous Period of the

Paleozoic Era or to the rocks formed during that period; also, referring to something that includes or produces carbon.

Coal is a CARBONIFEROUS *deposit.*

carbon monoxide \'kär-bən mə-'näk-ˌsīd\
CHEMISTRY. CO. A compound of carbon and oxygen that is colorless, odorless and highly poisonous.

CARBON MONOXIDE *is generally produced in the absence of enough oxygen to oxidize the burning carbon completely.*



CARDIAC MUSCLE

carbon tetrachloride \'kär-bən ˌte-trə-'klō(ə)r-ˌīd\
CHEMISTRY. CCl_4. A colorless, strong-smelling, nonflammable compound of carbon and chlorine that is liquid at ordinary temperatures and easily evaporated.

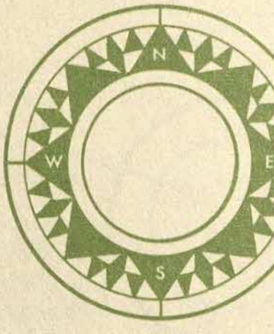
Because CARBON TETRACHLORIDE *is a good solvent, it is commonly used in dry cleaning, but must be handled with care because it is quite toxic.*

carcinogen \kär-'sin-ə-jən\ *n.*
PHYSIOLOGY. Any substance that can produce cancer.

The Food and Drug Administration of the United States inspects foods and drugs to make sure they do not contain a CARCINOGEN.

cardiac muscle \'kärd-ē-ˌak 'məs-əl\
ANATOMY and ZOOLOGY. The main muscle tissue of the heart of both vertebrate and invertebrate animals.

CARDIAC MUSCLE *is characterized by rhythmic contractions.*



CARDINAL POINTS OF THE COMPASS

cardinal number \'kärd-nəl 'nəm-bər\
MATHEMATICS. A number used to indicate how many objects are found in a set, as opposed to a number used to show the order of objects in a set; see *ordinal number.*

The CARDINAL NUMBER *of the set of even numbers between 5 and 25 is 10.*

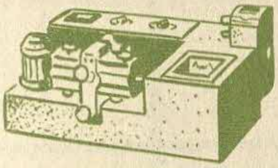
cardinal points of the compass \'kärd-nəl 'pȯints əv thə 'kəm-pəs\
The four main points of the compass: north, south, east and west.

A mariner's compass has seven points between each of the CARDINAL POINTS OF THE COMPASS.

cardiogram \'kärd-ē-ə-ˌgram\ *n.*

MEDICINE. A graphic tracing of the heart's action, made by means of a cardiograph.

A physician uses a CARDIOGRAM *as an aid in diagnosing heart ailments.*



CARDIOGRAPH

cardiograph \'kärd-ē-ə-ˌgraf\ *n.*

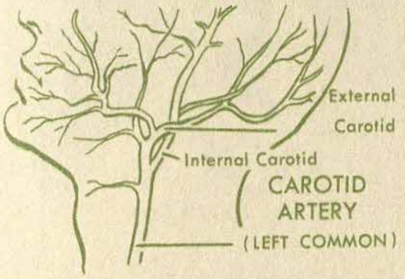
MEDICINE. An instrument used to make a cardiogram, a graphic tracing of the heart's action.

A CARDIOGRAPH *includes electrodes that detect the electrical impulses of the heart and an instrument to record those impulses.*

carnivore \'kär-nə-ˌvō(ə)r\ *n.*

1. ZOOLOGY. An animal that eats flesh. 2. BOTANY. Plants, such as the Venus flytrap, that absorb animal substances as food.

A lion is a CARNIVORE.



carotene \'kar-ə-ˌtēn\ *n.*

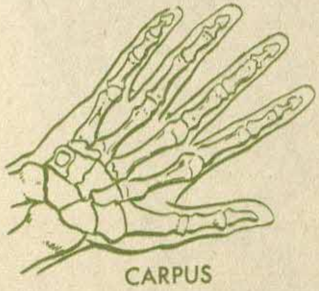
BIOLOGY. $C_{40}H_{56}$. A yellow or orange compound found in certain plants. When carotene is consumed, vitamin A is produced from it in the liver.

The yellow pigments of CAROTENE *and xanthophyll are evident in the coloration of many autumn leaves.*

carotid artery \kə-'rät-əd 'ärt-ə-rē\

ANATOMY. One of two major blood vessels (left or right) in the neck. Both carry blood from the aorta to the head and brain.

The CAROTID ARTERY *has two main divisions: internal and external.*



CARPUS

carpel \'kär-pəl\ *n.*

BOTANY. A modified floral leaf that, alone or with others, forms a pistil.

The CARPEL *of the sweet pea develops into the pod.*

carpus \'kär-pəs\ *n.*

ANATOMY. The wrist; the series of bones arranged in two irregular rows of four each.

In the human wrist, the CARPUS *is connected to the forearm by a disk of fiberlike cartilage.*

carrier \\'kar-ē-ər\\ *n.*

MEDICINE. A person or animal who shows no symptoms of a disease, but who carries within his body disease germs that may infect others.

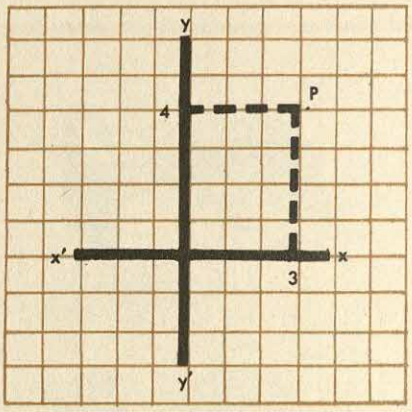
An epidemic of typhoid fever sometimes can be traced to an active CARRIER *of that disease.*

carrier wave \\'kar-ē-ər 'wāv\\

ENGINEERING. The unmodulated electromagnetic wave used at a particular frequency by a radio or television transmitting station.

A CARRIER WAVE *must be modulated to transmit sound.*

Finding P when x = 3, y = 4



CARTESIAN COORDINATE SYSTEM

Cartesian coordinate system \\kär-'tē-zhən kō-'ȯrd-nət 'sis-təm\\

MATHEMATICS. A graphical device by which coordinates, indicated by pairs of numbers, are used to locate points in a plane relative to two intersecting straight lines called the axes (x-axis and y-axis) of the system. The system may be extended to locate points in a three-dimensional space by using a third axis (z-axis) that intersects the other two axes in a common point. An ordered triple, or set of three numbers, is used to locate a point in a three-dimensional space.

If the axes of a CARTESIAN COORDINATE SYSTEM *are perpendicular to each other, the system is called a rectangular coordinate system.*

cartilage \\'kärt-ᵊl-ij\\ *n.*

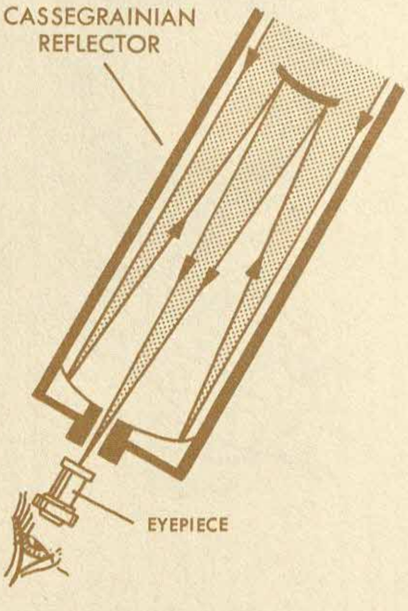
ANATOMY and ZOOLOGY. The gristle or the white, elastic connective tissue that joins the bones; also, the tissue that makes up the skeletons of embryos and young animals and that develops later into bones.

The external ear contains some CARTILAGE.

casein \\kā-'sēn\\ *n.*

CHEMISTRY. A protein obtained from fresh skim milk and combined with formaldehyde to produce plastics.

Plastics made from CASEIN *have moderate strength but are damaged by moisture and heat.*



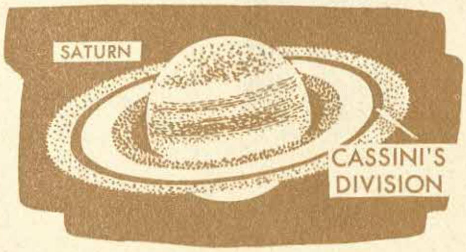
Cassegrainian reflector \\ˌkas-ə-'grān-ē-ən ri-'flek-tər\\

ASTRONOMY. A reflecting telescope in which light is reflected from a concave primary mirror to a convex secondary mirror located at the opposite end of the barrel, and then back through a hole in the center of the primary mirror to an eyepiece or camera.

The CASSEGRAINIAN REFLECTOR *has the advantages of being relatively compact and of allowing the observer to work at the lower end of the telescope.*

Cassini's division \kə-ˈsē-nez də-ˈvizh-ən\

ASTRONOMY. The gap, or dark space, between the two outer rings of the planet Saturn.



Astronomers estimate that CASSINI'S DIVISION *is about 3,000 miles wide.*

cassiterite \kə-ˈsit-ə-ˌrīt\ *n.*

EARTH SCIENCE. SnO_2. A mineral, tin dioxide, usually brown or black, with hardness, 6-7 and specific gravity, 6.8-7.1. It is the principal ore of tin and is sometimes loosely called tin.

There are no deposits of CASSITERITE *in the United States large enough to mine commercially.*

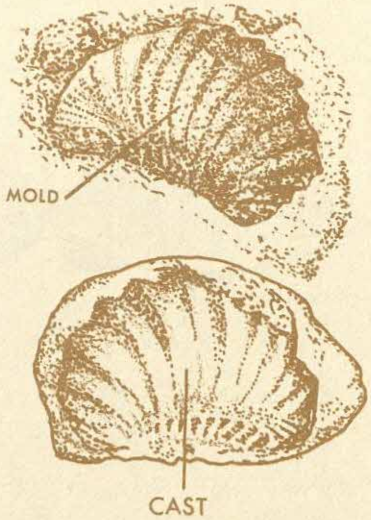
cast \ˈkast\ *n.*

EARTH SCIENCE. A type of fossil in which a mineral has filled the cavity, or mold, formed by the decay or solution of a solid plant or animal part; also, an artificial replica of a fossil or other object made from a mold.

A CAST *reproduces only the shape of the original object.*

catabolism \kə-ˈtab-ə-ˌliz-əm\ *n.*

BIOLOGY and PHYSIOLOGY. Any process in which living cells convert complex substances into more simple compounds; destructive metabolism.



Carbon dioxide is a product of CATABOLISM *in plants and animals.*

catadromous \kə-ˈtad-rə-məs\ *adj.*

ZOOLOGY. Referring to a freshwater organism that spawns in salt water.

Eels are among the better-known CATADROMOUS *fishes.*

catalysis \kə-ˈtal-ə-səs\ *n.*

CHEMISTRY. A means of speeding up or slowing down a chemical reaction by adding an element or compound that, although it remains unchanged, reduces the energy needed for the reaction to proceed (positive catalysis) or increases the energy needed for the reaction to proceed (negative catalysis).

In one laboratory method for the preparation of oxygen, manganese dioxide (MnO_2) permits positive CATALYSIS *of heated potassium chlorate ($KClO_3$).*

catalyst \'kat-ᵊl-əst\ *n.*

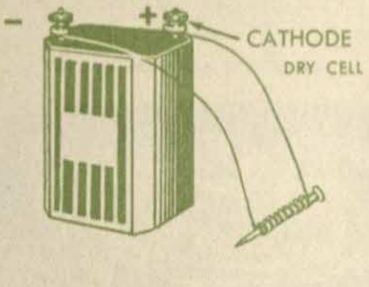
CHEMISTRY. A substance that either speeds or slows a chemical action but does not itself undergo a permanent chemical change; a catalytic agent.

Some paint products contain a CATALYST *that speeds drying.*

catastrophism \kə-'tas-trə-ˌfiz-əm\ *n.*

EARTH SCIENCE. The hypothesis that changes in the earth's crust were caused by sudden, violent geologic disturbances that also destroyed the earth's plant and animal life. Based on the evidence of widely-differing fossils found in successive beds of rock, the belief was most prevalent in the fifteenth, sixteenth and seventeenth centuries.

CATASTROPHISM *assumes destruction of existing life forms by a catastrophe and replacement of them by different forms.*



cathode \'kath-ˌōd\ *n.*

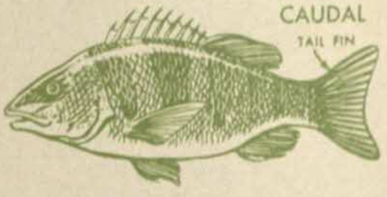
1. CHEMISTRY and PHYSICS. The negative terminal of an electroplating cell; therefore, the electrode at which electrons are taken on by an element or ion and at which reduction occurs; also, the positive terminal of a battery as the battery is discharged. 2. ENGINEERING. The electrode that gives off electrons in an electron tube, such as a radio tube.

The CATHODE *is the electron-poor electrode in a storage battery.*

cathode rays \'kath-ˌōd 'rāz\

PHYSICS. A flow of electrons driven at high speed from the heated cathode of a vacuum tube by its high negative voltage.

CATHODE RAYS *can be deflected if a magnet is so placed that the rays pass through the magnetic field.*



cation \'kat-ˌī-ən\ *n.*

CHEMISTRY and PHYSICS. An ion having a positive electric charge; the ion that moves toward the cathode in an electrolytic solution used in electrolysis.

In a hydrochloric acid solution, the hydrogen ion is the CATION.

caudal \'kȯd-ᵊl\ *adj.*

ANATOMY and ZOOLOGY. Referring to a tail.

The CAUDAL *fin of a fish is its principal organ of locomotion.*

caustic \'kȯ-stik\ *n.*

1. CHEMISTRY. Any corrosive substance, but especially sodium and potassium hydroxides. 2. MEDICINE. A substance that destroys living tissue.

Silver nitrate is known as a CAUSTIC *because it is a strong oxidizing agent.*

cc.

An abbreviation for cubic centimeter. See *cubic centimeter.*

CECUM

cecum \'sē-kəm\ *n.*

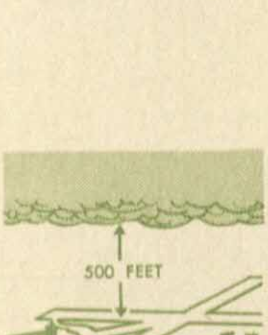
ANATOMY and ZOOLOGY. A pouchlike cavity having only one opening, as, in man, the beginning of the large intestine.

In man, the small and large intestine and the vermiform appendix open into the CECUM, *an intestinal pouch.*

ceiling \'sē-liŋ\ *n.*

1. EARTH SCIENCE. The height of the base of a cloud layer when more than half of the sky is overcast. 2. AERONAUTICS. The greatest altitude at which a given airplane can fly in horizontal flight.

A thin or transparent cloud cover is not considered a CEILING.



CEILING

celestial equator \sə-'les(h)-chəl i-'kwāt-ər\

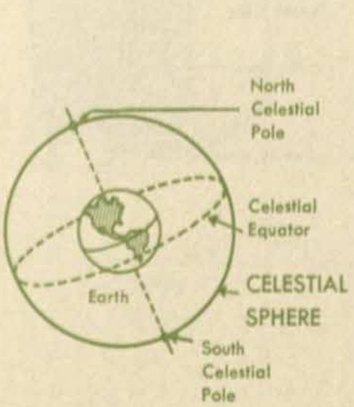
ASTRONOMY. The imaginary circle on the celestial sphere that lies in the same plane as the earth's equator and is located halfway between the celestial poles.

Astronomers use the CELESTIAL EQUATOR *as a reference line in describing the position of celestial objects.*

celestial mechanics \sə-'les(h)-chəl mi-'kan-iks\

ASTRONOMY. The branch of astronomy that uses the principles of theoretical mechanics to deal with the motion of celestial bodies as they are affected by the forces of gravitation.

By the use of CELESTIAL MECHANICS, *the position of the planets can be predicted with accuracy.*



CELESTIAL SPHERE

celestial pole \sə-'les(h)-chəl 'pōl\

ASTRONOMY. Either of the two points on the celestial sphere that are imaginary extensions of the earth's axis.

The celestial meridian is an imaginary great circle that passes through both the north and the south CELESTIAL POLE *and through the observer's zenith.*

celestial sphere \sə-'les(h)-chəl 'sfi(ə)r\

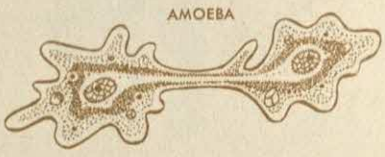
ASTRONOMY. An imaginary sphere extending outward from the earth for an infinite distance and on whose surface the objects in space appear to be located. It is divided by imaginary lines so that celestial bodies can be located at particular points on it.

Because of the daily rotation of the earth, the CELESTIAL SPHERE *appears to turn.*

cell \'sel\ *n.*

1. BIOLOGY. In living tissue, the smallest structural and functional unit (characterized by a nucleus and cytoplasm); also, a walled cavity in the nonliving tissues of plants. 2. PHYSICS. A container or compartment in which electrodes in an electrolytic solution generate electricity, as in a car battery. 3. CHEMISTRY. A container with electrodes in an electrolytic solution, used in electroplating metals. One electrode (negative) is the object to be plated, and the electrolytic solution contains ions of that metal.

The size of a single CELL *may range from that of a bacterium to that of an unfertilized ostrich egg.*



CELL DIVISION

cell differentiation \'sel ˌdif-ə-ˌren-chē-'ā-shən\

BIOLOGY. The process by which embryonic cells change in respect to the structure and function they serve.

CELL DIFFERENTIATION *takes place in the developing embryo as similar cells of the dividing zygote develop into the dissimilar cells of blood, skin, nerves, bone and muscle.*

cell division \'sel də-'vizh-ən\

BIOLOGY. The process by which single-celled plants and animals reproduce; also, the process by which new cells are formed in multicellular animals; see *mitosis* and *meiosis.*

The steps in CELL DIVISION *are often classified under five headings: interphase, prophase, metaphase, anaphase and telephase.*

cell membrane \'sel 'mem-ˌbrān\

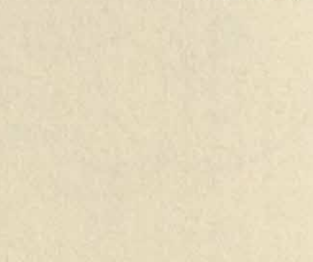
BIOLOGY. The thin, living tissue that surrounds the materials of a cell.

Substances that enter and leave a cell must pass through the CELL MEMBRANE.

cell sap \'sel 'sap\

BOTANY. A liquid that fills the vacuoles in plant cells and is composed of water in which substances are dissolved or colloidally dispersed.

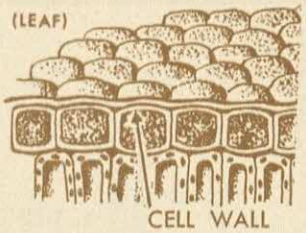
CELL SAP *is a nonliving part of a plant cell.*



cellulose \'sel-yə-ˌlōs\ *n.*

BIOLOGY and CHEMISTRY. $(C_6H_{10}O_5)_x$. A carbohydrate that is the chief part of the cell walls of plants.

Man's digestive system cannot digest CELLULOSE.



cell wall \\'sel wȯl\\

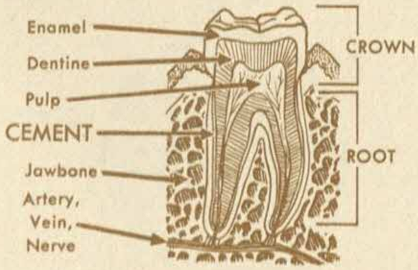
1. BOTANY. The outer, nonliving wall that surrounds plant cells, composed mainly of cellulose. 2. ZOOLOGY. A wall, composed of nonliving material, that surrounds cells in bone and cartilage but is not found in most other animal tissue.

The CELL WALL *in such soft plant parts as leaves and petals is thin and easily crushed, but in wood cells it is very thick.*

Celsius temperature scale \\'sel-sē-əs 'tem-pər-ˌchu̇(ə)r 'skāl\\
Another name for Centigrade temperature scale. See *Centigrade temperature scale.*

cement \\si-'ment\\ *n.*

1. ANATOMY. The hard outer crust of the root of a tooth; cementum. 2. CHEMISTRY. A mixture of such complex silicates as aluminum, iron and magnesium. When mixed with water and aggregates, the mixture hardens, forming a durable building material.



Enamel covers the dentine in the crown of a tooth, while CEMENT *covers the dentine in the root.*

center \\'sent-ər\\ *n.*

1. MATHEMATICS. The point about which a curve, particularly a conic section, is symmetrical; also, the point within a circle or sphere that is equidistant from all points on the circle or sphere. 2. PHYSIOLOGY. A collection of nerve cells that control a common function, such as breathing or heartbeat.

The perpendicular bisector of a chord of a circle passes through the CENTER *of the circle.*

center of curvature \\'sent-ər əv 'kər-və-ˌchu̇(ə)r\\
MATHEMATICS. The center of a circle tangent to the curve, the curvature being considered equal on both sides at the point of tangency; also called circle of curvature.

CENTER OF CURVATURE *is commonly used to denote a point within a circle or elipse.*

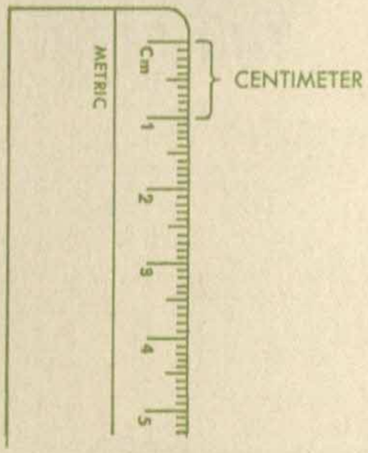
center of gravity \\'sent-ər əv 'grav-ət-ē\\
PHYSICS. That point in an object about which the mass (or weight) is evenly distributed in all directions.

A racing car is designed with a low CENTER OF GRAVITY *to resist tipping on curves.*

center of mass \'sent-ər əv 'mas\

ASTRONAUTICS and PHYSICS. That point in an object about which matter is evenly distributed. It is the mean position within the object.

If a body is composed of a homogenous material, its CENTER OF MASS *will coincide with its center of gravity.*



Centigrade temperature scale \'sent-ə-ˌgrād 'tem-pər-ˌchu̇(ə)r 'skāl\

CHEMISTRY and PHYSICS. A temperature scale using the melting point of ice at sea level as 0° and the boiling point of water at sea level as 100°; abbreviation for a given point on the scale is C.

The CENTIGRADE TEMPERATURE SCALE *is known also as the Celsius temperature scale.*

centimeter \'sent-ə-ˌmēt-ər\ *n.*

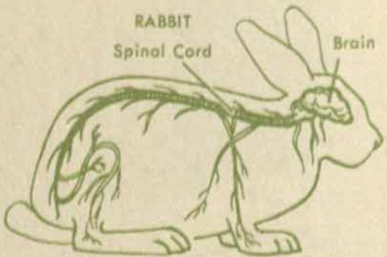
MATHEMATICS. A unit of length in the metric system equal to 0.01 meter or 0.3937 inch.

A CENTIMETER *is equal to approximately ⅜ of an inch.*

centimeter-gram-second system \'sent-ə-ˌmēt-ər 'gram 'sekənd 'sis-təm\

PHYSICS. A system of measurement based on the fundamental units of distance (centimeter), mass (gram) and time (second); *abbr.* cgs.

A dyne is a unit of force in the CENTIMETER-GRAM-SECOND SYSTEM *and is equal to the force required to accelerate a mass of one gram one centimeter per second.*



CENTRAL NERVOUS SYSTEM

central cylinder \'sen-trəl 'sil-ən-dər\

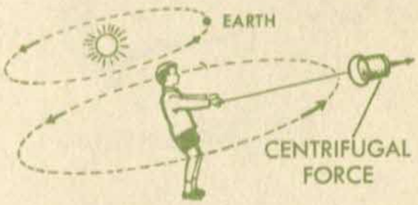
BOTANY. The central core, or stele, of the root of a plant; composed mainly of xylem and phloem tissue.

Water and dissolved minerals move upward through the CENTRAL CYLINDER *of a plant to the stem and leaves.*

central nervous system \'sen-trəl 'nərv-əs 'sis-təm\

ANATOMY. That part of the nervous system that receives sensory impulses and sends out motor impulses.

In vertebrates, the CENTRAL NERVOUS SYSTEM *is composed of the spinal cord and the brain.*



centrifugal force \sen-'trif-yə-gəl 'fō(ə)rs\
PHYSICS. The force exerted outward from the center of rotation on a body moving in a curved path.

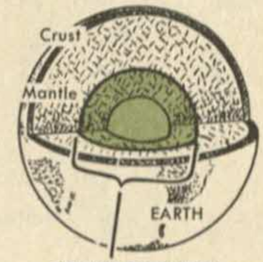
The CENTRIFUGAL FORCE *resulting from the revolution of the earth around the sun is balanced by the gravitational force between the two bodies.*

centrifuge \'sen-trə-ˌfyüj\ *n.*
A machine having a rotating container in which centrifugal force separates substances of different densities.

Cream can be separated from milk in a CENTRIFUGE.

centripetal force \sen-'trip-ət-ᵊl 'fō(ə)rs\
PHYSICS. The inward force acting on a body moving in a curve or circle. The force is directed toward the center of the curve or circle and keeps the body in a circular path. It is the opposite of centrifugal force.

The gravitational pull of the earth is the CENTRIPETAL FORCE *on an orbiting satellite.*



CENTROSPHERE

centrosphere \'sen-trə-ˌsfi(ə)r\ *n.*
EARTH SCIENCE. The dense core of the earth that comprises most of the earth's mass.

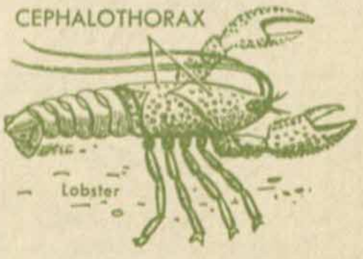
The CENTROSPHERE *has a radius of about 2,100 miles.*

cephalic \sə-'fal-ik\ *adj.*
ANATOMY and ZOOLOGY. Pertaining to the head.

The CEPHALIC *structure of the ape is similar to man's.*

cephalothorax \ˌsef-ə-lō-'thō(ə)r-ˌaks\ *n.*
ZOOLOGY. The region of the combined head and thorax in spiders and certain crustaceans.

The CEPHALOTHORAX *of the crayfish is covered by a hard shell or covering known as a carapace.*



cepheid \'sē-fē-əd\ *n.*
ASTRONOMY. One of a class of stars that pulsates and whose variations of brightness occur regularly.

By comparing the period of variation and the brightness of a EPHEID, *astronomers have been better able to estimate distances in space.*

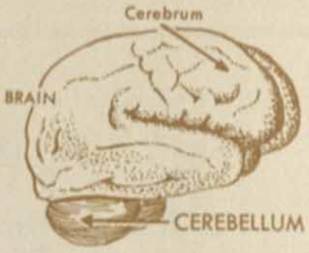
cervical \'sər-vi-kəl\ *adj.*
ANATOMY. Pertaining to the neck.

In man, there are seven CERVICAL *vertebrae.*

cerebellum \\,ser-ə-'bel-əm\\ *n.*

ANATOMY and ZOOLOGY. A section of the brain that functions as the coordinating center for muscular movement and that is located behind and below the cerebrum.

The surface of the CEREBELLUM *consists of gray matter and the interior consists of white matter.*



cerebral cortex \\sə-'rē-brəl 'kȯr-,teks\\

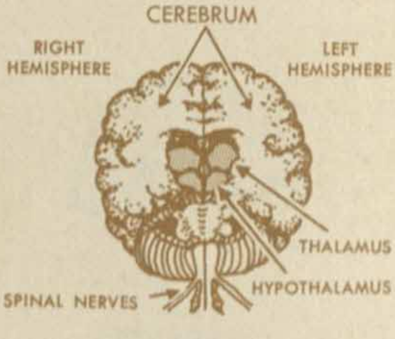
ANATOMY. The outer layer of gray matter, composed of nerve cell bodies, that covers the cerebrum.

The activities of the CEREBRAL CORTEX *can be detected as electrical impulses.*

cerebral hemisphere \\sə-'rē-brəl 'hem-ə-,sfi(ə)r\\

ANATOMY. Either the left or right half of the cerebrum.

Both the left CEREBRAL HEMISPHERE *and the right develop from the forebrain.*



BRAIN
(Front view)

cerebrospinal fluid \\sə-,rē-brō-'spīn-ᵊl 'flü-əd\\

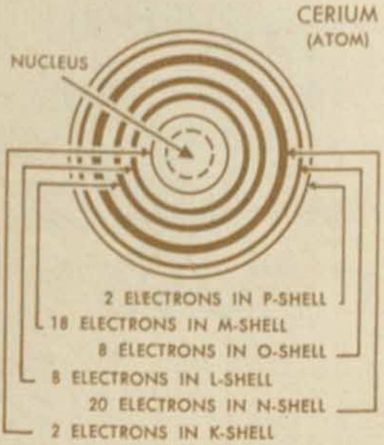
PHYSIOLOGY and ZOOLOGY. A watery, alkaline fluid that circulates beneath the covering, or meninges, of the brain and spinal cord. It is extracted from the blood through special structures in the brain and is reabsorbed into the blood through special structures along the central nervous system.

CEREBROSPINAL FLUID *helps maintain equalized pressure in the brain and spinal cord and acts as a shock absorber.*

cerebrospinal nervous system \\sə-,rē-brō-'spīn-ᵊl 'nər-vəs 'sis-təm\\

ANATOMY and ZOOLOGY. The portion of the nervous system of vertebrates that involves nerves of the brain and spinal cord, its chief function being to route impulses from sense receptors to voluntary muscles.

The CEREBROSPINAL NERVOUS SYSTEM *is another term for the central nervous system.*



cerebrum \\sə-'rē-brəm\\ *n.*

ANATOMY. In man, the main part of the brain, occupying the upper part of the cranium and consisting of two equal hemispheres.

Experimental evidence indicates that man's CEREBRUM *controls conscious and voluntary processes.*

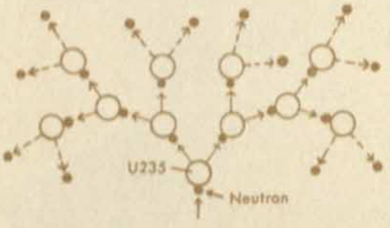
cerium \\'sir-ē-əm\\ *n.*

CHEMISTRY. A gray, metallic chemical element of the rare-earth group. Symbol, Ce; atomic number, 58; atomic weight, 140.12.

An alloy of CERIUM *and iron gives off sparks when struck with steel and is used to ignite the oxyacetylene gas in welding torches.*

cgs

An abbreviation for centimeter-gram-second. See *centimeter-gram-second system.*



CHAIN REACTION

chain \'chān\ *n.*

1. CHEMISTRY. A series of atoms, alike or unlike, connected by bonds. Chain generally refers to such a series of atoms in a compound as a carbon or a carbon-nitrogen series, but it also includes series of atoms in an element. 2. ENGINEERING. In surveying, a unit of measure equal to 66 feet; also, the surveying instrument that consists of 100 links, each link equal to 7.92 inches.

A CHAIN *of atoms in a carbon compound may be straight, as in normal butane, branched, as in isobutane, or closed, as in benzene.*

chain reaction \'chān rē-'ak-shən\

CHEMISTRY and PHYSICS. A continuing chemical process in which the energy released by one process promotes one or more other processes; also, a disintegrative process within the nuclei of atoms in which enough neutrons are released by fission to produce fission in nearby atoms until all fissionable atoms within range have been disintegrated.

Energy is released in a CHAIN REACTION *either by ordinary chemical processes or from the nuclei of disintegrating atoms.*

CHALCEDONY
ONYX

chalcedony \kal-'sed-ᵊn-ē\ *n.*

EARTH SCIENCE. A translucent form of quartz deposited from aqueous solutions. It is usually brown to gray in color with a waxy luster and is frequently found in rock cavities as a lining, or completely filling the cavity.

Agate and onyx consist of layered CHALCEDONY *with parallel bands of different colors.*

chalk \'chȯk\ *n.*

EARTH SCIENCE. A very soft form of limestone, white or gray-white in color and containing minute shells of calcium carbonate surrounded by very small calcite crystals.

CHALK *is used as a fertilizer and as a whitewash ingredient, in addition to its use in making the crayon used on chalkboards.*

chance \'chan(t)s\ *n.*

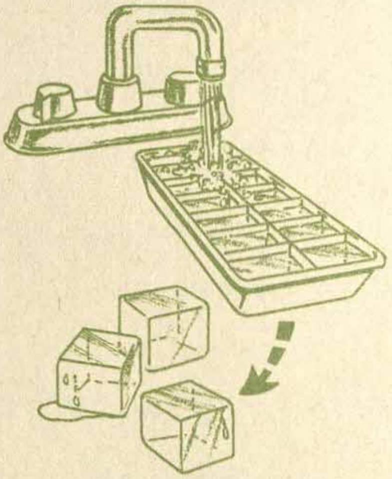
MATHEMATICS. The probability that a particular event will occur; a ratio between the number of ways an event may occur and the number of ways all related events may occur.

If a bag contains two marbles, one black and one red, then the CHANCE *of drawing the red marble without looking is one out of two.*

change of state \'chānj əv 'stāt\

PHYSICS. The transition of a substance from one form to another resulting in a specific alteration of its physical properties.

The conversion of water to ice is a CHANGE OF STATE.



CHANGE OF STATE

characteristic \ˌkar(-i)k-tə-'ris-tik\ *n.*

MATHEMATICS. The whole number or integer written to the left of the decimal point in a logarithm; the integral part of the logarithm.

In the logarithm 3.623 the CHARACTERISTIC *is 3.*

characteristics \ˌkar(-i)k-tə-'ris-tiks\ *n.*

BIOLOGY. In animals and plants, traits transmitted by heredity and modified by environment; such attributes as behavior, size, shape or hair color, by which an individual or a group can be recognized.

Two dominant CHARACTERISTICS *of the dogs called pointers are their keen senses of smell and vision.*

charcoal \'chär-ˌkōl\ *n.*

CHEMISTRY. An impure, porous form of carbon, characteristically black and brittle, that is produced when wood is heated in the absence of air.

CHARCOAL *is used as a reducing agent to remove the oxygen from metallic oxides and free the metal.*

CHARGE

charge \'chärj\

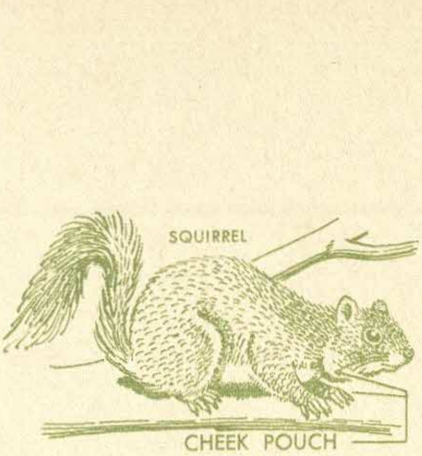
CHEMISTRY and PHYSICS. (V.) To convert electrical energy to chemical energy in a storage cell or battery so that the battery can be used as a source of electricity; also, to produce an excess of positive or negative electricity on an object by rubbing the object with another object. (N.) The quantity of electricity present on an object or in a region.

Direct current is used to CHARGE *a storage battery and is then drawn from the battery for various uses.*

Charles's law \'chärl-zəz 'lȯ\

CHEMISTRY and PHYSICS. A law stating that the volume of gas varies directly with the Kelvin temperature (Centigrade temperature plus 273), as long as the pressure remains constant.

CHARLES'S LAW *is valid only for ideal or perfect gases because real gases depart from it somewhat.*



cheek pouch \'chēk 'pau̇ch\

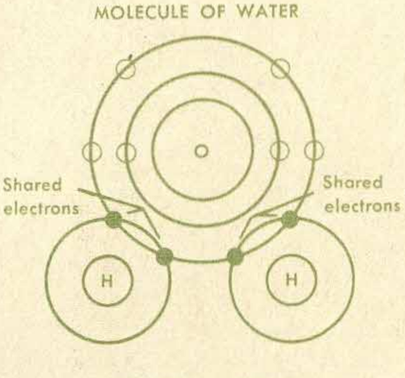
ZOOLOGY. A sac contained within the cheek of some animals and used for storing food.

A squirrel carries nuts in its CHEEK POUCH.

chemical \'kem-i-kəl\ *n.*

CHEMISTRY. An element or a compound of definite composition that can be represented by a symbol or a formula.

A reagant, such as sulfuric acid, that is produced and used in large quantities, sometimes in a crude or somewhat impure form, is referred to as a "heavy" CHEMICAL.



CHEMICAL BOND

chemical action \'kem-i-kəl 'ak-shən\

CHEMISTRY. A change in the chemical composition of a compound; a chemical reaction.

Energy is either produced by or required for a CHEMICAL ACTION.

chemical affinity \'kem-i-kəl ə-'fin-ət-ē\

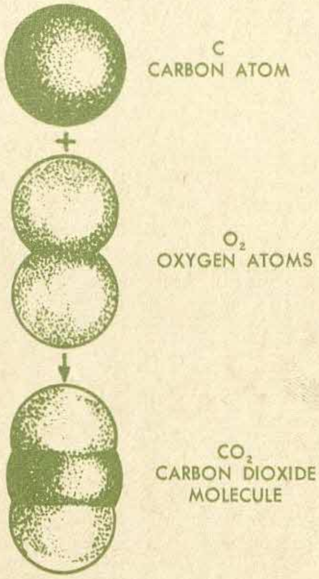
CHEMISTRY. The chemical property that determines which reaction will occur in a system in which various reactions could occur.

CHEMICAL AFFINITY *is also called the intensity factor of chemical energy.*

chemical bond \'kem-i-kəl 'bänd\

CHEMISTRY. The force that holds atoms together, forming molecules of elements or compounds.

A CHEMICAL BOND *is generally the result of atoms sharing or transferring electrons.*



CHEMICAL CHANGE

chemical change \'kem-i-kəl 'chānj\

CHEMISTRY. A change in chemical properties and composition; also, a chemical action or a chemical reaction; also, the formation of substances having chemical properties different from the substance or substances that entered into the chemical action.

Carbon and oxygen undergo a CHEMICAL CHANGE *when they combine to form carbon dioxide.*